SECTION 20 COMPLIANCE ASSESSMENT FOR CBNG PRODUCED WATER DISCHARGES BY WILLIAMS PRODUCTION RMT COMPANY TO DRY FORK POWDER RIVER, JOHNSON COUNTY, WYOMING

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EXECUTIVE SUMMARY

This report presents an assessment of the potential impacts to agricultural uses from the proposed discharge of Coalbed Natural Gas (CBNG) produced water to Dry Fork Powder River in Johnson County, Wyoming by Williams Production RMT Company. The water management strategy proposed by Williams for the Dry Fork Powder River CBNG Project calls for storage in on-channel reservoirs, with releases to Dry Fork Powder River when natural storm flows cause the on-channel reservoirs to overflow or when the landowner requests the water.

The purpose of this evaluation is to demonstrate that the proposed discharges will comply with Chapter 1, Section 20 of the Wyoming Water Quality Rules and Regulations. As such, a Tier 2 – Background Water Quality Analysis approach recommends EC effluent limits and SAR monitoring that will cause no harm to the existing agricultural uses. This approach incorporated a field investigation consisting of soil and vegetation sampling in three fields adjacent to Dry Fork Powder River.

Soil sampling in the Dry Fork Powder River fields revealed the presence of saline and saline-sodic soils. Saline-sodic soils exist when there is sufficient sodium in the soil to affect crop production (ESP greater than 15 percent) and where there are excessive quantities of soluble salts in the soil (EC greater than 4 dS/m).

Comparing soil conditions in the Dry Fork Powder River with the expected CBNG produced water quality reveals that no decreases in agricultural production will result. The CBNG produced water from the Dry Fork Powder River project area has an EC that ranges from 1.1 to 3.4 dS/m, while the estimated historic water quality of Dry Fork Powder River has an EC of 4.6 dS/m. Average EC values in soils historically irrigated by the Dry Fork Powder River, to a depth of 48 inches, range from 3.5 to 9.2 dS/m. Thus, no increase in soil EC should occur with application of CBNG produced water.

Based on the analysis presented herein, an EC effluent limit above the confluence of House Creek and Dry Fork Powder River that will cause no degradation to existing soil and vegetation conditions and agricultural uses on Dry Fork Powder River is 3.1 dS/m. It is further recommended that the outfalls located in the House Creek drainage have an EC limit of 7.5 dS/m which is currently the effluent limit for numerous permits within the Dry Fork Powder River watershed. It is recommended that an IMP be located above the most upstream agriculturally significant field to monitor SAR. The EC/SAR relationship at this location should not exceed the “No reduction in infiltration” line (Ayers and Westcot, 1985). At the recommended EC effluent limit, and associated IMP monitoring for SAR CBNG discharge into Dry Fork Powder River or its tributaries by Williams will not result in a measurable decrease in crop or livestock production.

1.0 INTRODUCTION

This report presents an assessment of potential impacts to agricultural practices along the Dry Fork Powder River (Dry Fork) and proposes effluent limits for the proposed discharge of coalbed natural gas (CBNG) produced water to the Dry Fork and its tributaries in Johnson County, Wyoming. The discharge of produced water will be from Williams Production RMT Company (Williams). This assessment incorporates a Tier 2 – Background Water Quality Analysis approach to demonstrate compliance with Chapter 1, Section 20 of the Wyoming Water Quality Rules and Regulations, which state:

> *"All Wyoming surface waters which have the natural water quality potential for use as an agricultural water supply shall be maintained at a quality which allows continued use of such waters for agricultural purposes. Degradation of such waters shall not be of such an extent to cause a measurable decrease in crop or livestock production. Unless otherwise demonstrated, all Wyoming surface waters have the natural water quality potential for use as an agricultural water supply."*

The Tier 2 – Background Water Quality Analysis approach defines effluent limits as equal to or less than that of background water quality conditions. To obtain estimates of background water quality on intermittent or ephemeral stream channels such as the Dry Fork, soil sampling is conducted to obtain EC and SAR of land historically irrigated, naturally or artificially, with the subject stream.

To identify suitable areas for soil sampling, 38 miles of the Dry Fork stream channel were surveyed for the presence of naturally and/or artificially irrigated areas. Naturally irrigated soils are often located on floodplain landscape positions, usually immediately adjacent to the primary channel. These areas support vegetation types and densities that indicate they receive more water than the surrounding landscape. This additional water is due to occasional flooding or the existence of a high water table, with the Dry Fork being the primary source for both.

The initial assessment resulted in the identification of 17 fields that potentially are or have been naturally irrigated. No artificially irrigated fields were identified within the surveyed area. Field investigation verified that three of the 17 identified fields met WDEQ standards for protection under Section 20, were within the mainstem of the Dry Fork, and were not potentially influenced by previous CBNG produced water discharge. These three fields represent baseline conditions and are therefore the subject of this assessment.

The analysis presented herein demonstrates whether produced water discharged by Williams into the Dry Fork and its tributaries will result in degradation of background water quality leading to a measurable decrease in crop and/or livestock production. Soil scientists and a rangeland plant ecologist from KC Harvey, Inc. conducted a site investigation including soil sampling, vegetation survey and data analysis, of the three naturally irrigated fields along the mainstem of Dry Fork. These data, along with data regarding proposed discharge water quality, site conditions, and water management strategies were used to evaluate whether there would be a measurable decrease in crop and/or livestock production downstream of the proposed discharge sites.

2.0 METHODS

This section describes methods used for defining background water quality and establishing effluent limits in the Dry Fork. This includes the identification of fields suitable for sampling, sampling protocol, and methods of soil statistical analysis.

2.1 Identification of Naturally Irrigated Areas

Four tasks allowed identification of naturally irrigated areas; spatial analysis of aerial photos of the Dry Fork channel area, field checking of areas identified through the spatial analysis, an aerial reconnaissance flight, and a search through the Wyoming SEO water rights database. Areas identified through this process then received soil sampling and vegetation survey (Section 2.2).

2.1.1 Spatial Analysis of Aerial Photos

The spatial analysis of aerial photos used color infrared (CIR) aerial photography collected in 2002, within a geographic information system (GIS). Analysis was restricted to a 600 foot wide buffer zone adjacent to the stream channel, roughly approximating the stream corridor. The analysis involved calculation of the Normalized Difference Vegetation Index (NDVI) for each pixel in the photography (Kidwell, 1990). NDVI is a simple formula using the spectral values of the near infra-red (NIR) and red bands of the imagery.

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)}$$

Green vegetation reflects well in the NIR band and poorly in the visible (red and other) bands. If there is much more reflected radiation in near-infrared wavelengths than in visible wavelengths, then the green vegetation in that pixel is likely to be dense. If there is very little difference in the intensity of visible and near-infrared wavelengths reflected,

then the green vegetation is sparse. The equation yields NDVI values from -1 to 1 and values close to 1 indicate the highest density of green vegetation.

Analysis of the CIR imagery with the GIS allowed calculation of an NDVI value for each pixel within the stream corridor buffer. Visual analysis of the results allowed selection of a threshold NDVI value. Areas with pixel values above this threshold have higher densities of green vegetation representative of sub-irrigated areas. Seventeen areas meeting this criterion, and greater than five acres in size were targeted for field checking.

2.1.2 Field Investigation of Areas Identified in the Aerial Photo Analysis

Following the analysis of aerial photography, a field investigation determined whether or not the targeted areas are, or were historically irrigated through natural processes. The field investigation evaluated the targeted areas for landscape position relative to the Dry Fork channel, vegetation communities and density, and channel characteristics (depth of channel). Typically, naturally irrigated soils are located on floodplains adjacent to a shallow stream channel and support dense vegetation community types characteristic of an enhanced water supply.

An evaluation of historic permitted CBNG discharge in the Dry Fork channel provided an additional screening of whether target areas should be sampled. If an identified naturally irrigated area received CBNG discharge in the past, soil and vegetation sampling was not conducted.

The field investigation confirmed that three of the 17 areas identified in the aerial photo analysis are naturally irrigated, where along the mainstem of the Dry Fork, and have not received CBNG discharge. Therefore, these areas are large enough to be agriculturally significant, and were suitable for sampling to estimate historical water quality and develop appropriate effluent limits to protect agricultural uses adjacent to the Dry Fork. The three fields range in size from 22-47 acres.

The following assessment includes data from fields located along the mainstem of the Dry Fork (Figure 2). The three fields are labeled Field A, Field B, and Field D (Field C was originally sampled, but is not included in this analysis as it is located along House Creek, a tributary of the Dry Fork). Locations are as follows:

- Field A: T42N, R77W, Sections 23 and 24,
- Field B: T43N, R77W, Sections 24 and 25, and T43N, R76W, Section 30,
- Field D: T43N, R77W, Section 24

2.1.3 Aerial Reconnaissance

KC Harvey, Inc. conducted a low altitude aerial reconnaissance of the Dry Fork from a small fixed-wing aircraft to assess the entire drainage visually from the air. This visual

assessment of the drainage revealed no additional naturally irrigated areas and confirmed that the aerial photo analysis identified all relevant areas.

2.1.4 SEO Water Rights Search

A search of the Wyoming State Engineers Office water rights database revealed that there are currently no surface water rights or permitted irrigation diversions on the main branch of the Dry Fork. The field reconnaissance and aerial reconnaissance also verified that no artificially irrigated areas are present.

2.2 Sampling and Analysis of Naturally Irrigated Areas

Completion of the Section 20 analysis required sampling and analysis of soils and vegetation. The following describes methods used.

2.2.1 Soil Sampling

Soil scientists from KC Harvey, Inc. conducted soil sampling in the four identified agriculturally significant fields along the Dry Fork July 10th through 12th, 2007. Soil samples were collected in each field from seven to 10 locations, depending on the size of the field. A handheld global positioning system (GPS) recorded each sampling location. At each sample location, soil samples were collected from six depth increments; 0 to 6, 6 to 12, 12 to 24, 24 to 36, 36 to 48, and 48 to 72 inches using a truck-mounted Giddings Probe (Giddings Machine Company, Windsor, Colorado). Samples from each area were then composited by depth increment, yielding six samples per field.

Subsequent analysis of the soil samples at Energy Laboratories, Inc. (Helena, Montana) included measurements of the following soil parameters:

- pH,
- electrical conductivity (EC),
- dissolved calcium,
- dissolved magnesium,
- dissolved sodium,
- sodium adsorption ratio (SAR),
- saturation percentage,
- exchangeable sodium,
- exchangeable sodium percentage (ESP),
- cation exchange capacity (CEC),
- texture (percent sand, silt, and clay),
- percent lime,
- percent organic matter, and
- clay mineralogy (0-6 inch samples only).

Once the analysis was completed by the laboratory the soil sample data quality was reviewed in accordance with the “PARCC” parameters. The PARCC parameters; Precision, Accuracy, Repeatability, Completeness, and Comparability; are all indicators of data quality. Data collection methods that address these parameters ensure that data

are of known and acceptable quality and are therefore valid in representing the system sampled. Table 1 and Table 2 summarize the results of the physical and chemical soil analyses from the Dry Fork and Appendix A provides the original laboratory reports.

2.2.2 Vegetation Sampling

Vegetation surveys were conducted on the four fields within the Dry Fork study area, concurrent with soil sampling. Vegetation data collected consisted of randomly placing at least two 50 foot transects in areas representative of the field. Field size determined the number of transects used in each field. A 50 by 50 centimeter frame was placed every ten feet along each transect. Each species present within a frame was identified. If species were undecipherable (e.g. juvenile plants), they were grouped by life-form and designated weedy or desired species, with each species given a unique identification number (e.g. weedy forb 1, weedy forb 2). The range scientist recorded the canopy cover for each species, and for rock, bare ground and litter. Canopy cover is the percentage of the soil surface covered by the vertical projection of a species.

Analysis of the total canopy cover data allowed calculation of the vegetative canopy cover and the percent composition of each species. In addition, a list of all the species present in each field was generated, along with their relative abundance (high, moderate or low).

3.0 BASELINE CONDITIONS

Section 2.1 describes the identification of three naturally irrigated fields. All fields were sampled and analyzed.

3.1 Hydrology and Irrigation

The proposed CBNG produced water discharges will be into the Dry Fork and its tributaries. Dry Fork is an ephemeral stream that flows north-northwest and drains into the Powder River. Natural flow occurs in response to rainfall and snowmelt events; therefore the channel is periodically dry.

According to a search of the Wyoming State Engineer's Office water rights database, there are no permitted irrigation diversions on Dry Fork. As stated above, no artificially irrigated areas were identified during multiple field visits and aerial reconnaissance along the drainage. Natural irrigation through periodic flooding and/or a high water table occasionally occurs along Dry Fork. No naturally irrigated fields were identified below the confluence of Dry Fork and House Creek.

3.2 Surface Water Quality

An exhaustive search of several databases, including the United States Geological Survey database and the Wyoming Department of Environmental Quality website was completed. Historic water quality data are not available in the Dry Fork drainage or other similar, nearby drainages.

3.3 Vegetation

A mixture of native and non-native grasses, forbs, shrubs, and trees are present in each of the three mainstem fields studied. Appendix B lists the relative abundance and canopy cover of each species. The relatively abundant species are of primary importance in assessing impacts to agricultural uses from discharge of CBNG produced water.

Both desirable and undesirable grasses for agricultural use are present in the three assessed fields. Cheatgrass, field brome, and foxtail barley are the primary undesirable grasses present, while western wheatgrass, a desirable species, makes up a significant portion of the cover in each field. Western wheatgrass is the most productive forage grass in the fields (Table 3).

Forbs that make up greater than 1% of the total canopy cover within the identified fields are undesirable for agricultural use and mostly consist of Lambsquarters, common pepperwood, and thistle species. Field B in particular, has a high relative abundance of Lambsquarters and largely dominates the vegetation community.

3.4 Soil Conditions

Both county level NRCS soil surveys and soils data collected as part of this project describe baseline soil conditions. The following sections describe these in detail.

3.4.1 NRCS Soil Map Units

The Natural Resource Conservation Service (NRCS) Johnson County soil survey contains soil maps for the entire Dry Fork drainage (Figure 2). Several different soil map units are present in the assessed fields. Field A is located within the Kim-Haverson association, Field B is located within the Glenburg-Bankard and Haverson-Glenburg associations, and Field D is located within the Haverson-Glenburg association. The official NRCS descriptions for the Kim, Haverson, Glenburg, and Bankard soil series are included in Appendix C.

Kim soils are very deep, well drained soils that formed in alluvium and mixed eolian and alluvial material derived from sandstone and shale. Kim soils are generally found on alluvial fans below escarpments of sedimentary rock and uplands. Typical soil textures

are loam, sandy clay loam, or a clay loam; clay percentages usually range between 18 to 35 percent. Kim soils are moderately permeable and receive about 13 inches of precipitation annually. Common land uses of Kim soils include native pasture and some dry and irrigated cropping. Native vegetation typically consists of short grasses (National Cooperative Soil Survey, 2002b).

Haverson soils are very deep, well-drained soil that formed in alluvium from mixed sources. Haverson soils occupy floodplains and low terraces. Soil texture ranges from clay loam to sandy loam; clay percentages typically range from 18 to 35 percent. Haverson soils receive 14 to 18 inches of precipitation annually; spring and early summer report the most precipitation. Haverson soils are moderately permeable. The soils are used for pastureland or dryland crop production. Native vegetation usually includes mixed grasses, sagebrush, and cottonwoods (National Cooperative Soil Survey, 2002b).

Glenburg soils are very deep, well-drained soils that weathered from stratified alluvium rich in calcareous materials from mixed sources. Glenburg soils are generally found on floodplains and low terraces. Sandy loam is the most common soil texture and percent clay ranges from 5 to 18 percent. The mean annual precipitation is 12 inches, the bulk of which falls in the summer. Permeability is moderately rapid to rapid. Common land uses include grazing and dry and irrigated cropland. Vegetation includes native grasses such as: blue grama, western wheatgrass, and bluestem along with cottonwood stands (National Cooperative Soil Survey, 2005b).

Bankard soils are very deep, somewhat well-drained soil that formed in alluvium from mixed sources. Bankard soils occupy floodplains and low terraces. Texture is most commonly loamy sand and clay ranges from 10 to 15 percent. Precipitation peaks in the spring and early summer and ranges from 14 to 17 inches annually. Permeability is rapid to very rapid. Most Bankard soils serve as native pastureland and some are tilled. Native vegetation consists of cottonwood, grass, and brush (National Cooperative Soil Survey, 2002b).

3.4.2 Soil Physical Conditions

Soil physical properties affect aeration rates, water infiltration, water storage, and movement of water through the soil profile. Soil textures are primarily silty clay loam, clay loam, silty clay, and clay in Field B and Field D. Clay content ranges from 21 to 48 percent across all depths in these fields (Table 1). Field A has less clay, ranging from 16 to 26 percent. Field A consists of more sand than any of the other two fields. Thus, textures are sandy loam and sandy clay loam throughout the profile. Clay contents found in the soils at the Dry Fork site are comparable to other soils in the Powder River Basin.

Potential impacts to soils associated with sodic irrigation water may depend upon the clay mineralogy of the soil. X-ray diffraction (XRD) measured clay mineralogy in the surface soils (0 to 6 inches) of the three fields. Smectite composes 38 to 40 percent of the clay fraction; followed closely by illite and kaolinite, which range from 32 to 35 and 26 to 30 percent, respectively (Table 1). Smectitic clays are 2:1 clays that expand upon wetting and shrink after drying. Application of sodic waters to soils high in smectitic clays may increase the degree of swelling in these soils. Non-expanding clays, such as illite, kaolinite, and chlorite are less likely to be affected by sodic waters. In general these soils would be classified as having a mixed clay mineralogy, in comparison to being classified as smectitic or kaolinitic clay mineralogy.

Percent organic matter in the surface soil samples (0-6 inch) ranges from 2.5 to 4.0 percent (Table 1), typical of these soil types in the Powder River Basin.

3.4.3 Soil Chemical Conditions

Soil salinity is the amount of soluble salts in a soil and is often measured by using the electrical conductivity (EC) of a saturated paste extract. Salinity is important as high salt levels make it difficult for plants to obtain water (Bohn, et al., 1985). Soils with EC values greater than 4 dS/m are classified as saline. However, lower EC (2 dS/m) can affect sensitive plants while salt tolerant plants are productive at EC levels greater than 8 dS/m.

Soil EC ranged from 0.9 to 14.3 dS/m at the 0 to 72 inch depth increments in samples collected from the Dry Fork fields (Table 2). However, EC values of 10 dS/m or greater were measured in only two fields, Field A and Field D. The highest EC at any depth in Field B was 6.1 dS/m. Fields A and D, have their highest soil EC at the 12 to 24 inch depth increment, before falling off deeper in the soil profile. The highest EC value in Field B is deepest in the profile, from 48 to 72 inches. These values are comparable to the values reported for the Glenburg, Bankard, Haverson, and Kim soil series.

Average soil EC was calculated to a depth of 48 inches to assist in determining background water quality. As specified in the Agricultural Use Protection Policy, the 48 inch depth is representative of the average root zone depth of grass species present at the Dry Fork fields. Average soil EC ranged from 3.5 to 9.2 dS/m in the Dry Fork fields (Table 2). Two of the three fields sampled, (Field A and Field D) have average soil EC values of greater than 4.0 dS/m which classifies these soils as saline (Table 2). Only plants that are tolerant or moderately tolerant of soil salinity are well suited for growth on these fields. It should be noted that Field B had the lowest soil EC, but 50% of the vegetation present at the site is undesirable crop/range species.

Sodic soils are non-saline 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 clay 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 (Levy et al. 1998; Abrol et al., 1988; Evangelou, 1998; McNeal and Coleman, 1966; Sparks, 1995; Sumner et al., 1998; Shainberg et al., 1971; Soil Improvement Committee, California Plant Health Association, 2002). ESP is the amount of adsorbed sodium on soil exchange sites expressed as a percent of the cation exchange capacity (CEC) in milliequivalents per 100 grams of soil (meq/100 g):

$$ESP = \left(\frac{Exchangeable\ Sodium}{CEC} \right) \cdot 100$$

Soil ESP values range from 2.9 to 30 percent to a depth of 48 inches in the Dry Fork soil samples (Table 2). The average soil ESP ranges from 5.8 to 22.1 percent across the three fields. Sodic soil conditions exist naturally in Field A and Field D. When combined with the measured salinity, Field A and Field D are considered saline-sodic (Table 2). Saline-sodic soils are soils with ESP values greater than 15 percent, EC above 4 dS/m, and a pH of 8.5 or less (Brady, 1990; Soil Science Society of America, 2001). Saline-sodic soils are especially challenging to manage because the high salt content and the excess sodium ions affect plant growth. Therefore, Field A and Field D are naturally limited for crop production because of the enriched salinity and sodicity.

4.0 PROPOSED CBNG DISCHARGES

4.1 Water Management Strategy and Proposed Discharge Locations

The water management strategy for the Dry Fork CBNG Project calls for water storage in on-channel reservoirs, located on the Dry Fork or its tributaries. Proposed releases to the Dry Fork will only occur when natural storm flows cause the on-channel reservoirs to overflow or when the landowner requests the water. Williams has submitted complete documentation and specific locations of all reservoirs and outfalls as per WYDEQ permit application requirements.

4.2 Discharge Water Quality

Table 4 provides the water quality from twelve existing outfalls within the Bullwhacker project area. Williams has indicated that these data are from outfalls that represent the project area. Currently, the expected EC of the discharged produced water ranges from 1.1 to 3.4 dS/m, with an SAR of 6.5 to 22.3.

5.0 PROPOSED EFFLUENT LIMITS AND IMP STANDARDS

The "Tier 2 – Background Water Quality" approach included in the current draft Section 20 Agricultural Use Protection Policy (WYDEQ, 2007) is used herein to estimate the long-term average runoff water EC in Dry Fork and derive a proposed effluent limit for EC. As mentioned in Section 2.1.2, measured historic runoff water quality data are not available for the Dry Fork drainage. Thus, in this Tier 2 evaluation, the background water EC is estimated from the EC of soil samples collected from naturally irrigated fields downstream of the proposed discharges. Soil chemical conditions along Dry Fork are assumed to be in equilibrium with the runoff water chemistry supplied by Dry Fork over the long term. Soil chemistry, particularly soil ECe, is a function of the long-term average water quality received by the soil. The following equation is a frequently cited relationship that relates irrigation water quality to the soil ECe:

$$ECe = 1.5 \times ECw.$$

Where ECe is the average EC of the soil (measured in a saturated paste extract), and ECw is the long-term average EC of the applied water (Ayers and Westcot, 1985). The equation can be solved for the long-term average EC of the applied water such that:

$$ECw = ECe \div 1.5$$

The resultant equation, referenced in the current Section 20 Agricultural Use Protection Policy (WYDEQ, 2007), allows for the estimation of long-term average EC of the applied water, given that soil data have been collected at a specific site. The average soil ECe for the Dry Fork fields, to a depth of 48 inches is 6.9 dS/m (Table 2). Dividing the average soil ECe by the 1.5 concentration factor yields a corresponding ECw of 4.6 dS/m (4,600 micromhos/cm). In accordance with the Policy, 4.6 dS/m would be the proposed Tier 2 end-of-pipe EC limit for the outfalls above the agriculturally significant fields along Dry Fork. It is recommended that the outfalls located in the House Creek drainage have an EC end-of-pipe EC limit of 7.5 dS/m which is the permit limit on numerous permits within the Dry Fork drainage area. This recommendation is made due to the lack of agriculturally significant irrigation areas downstream of the confluence of House Creek and Dry Fork.

Based on previous permits issued in the Powder River Basin of Wyoming, the WDEQ has provided a level of conservatism to effluent limits using statistical methods. The statistical methods used include an outlier test, mean ECe, and 95% confidence intervals. Using these tests assumes that the collected data is normally distributed. Therefore before any statistical analysis was performed the data was analyzed using SPPS software (SPSS, 2001) to determine if the data has a normal distribution. Results indicate that the data are normally distributed. Therefore, it is appropriate to use basic T based statistics for the analysis.

An outlier test was performed on the data from the three fields along the mainstem of Dry Fork using SPSS (SPSS, 2001). The outlier test indicates that all of the data is acceptable for use. A mean ECe, standard deviation, and 95% confidence interval were then calculated using SPSS (SPSS, 2001). As stated above, the mean soil EC is 6.9 dS/m with a standard deviation of 3.5 and a lower bound 95% confidence interval of 4.6 dS/m. Therefore the recommended end-of-pipe effluent limit for ECw would be 3.1 dS/m.

In addition to the end-of-pipe EC limit, it is proposed that any resultant WYPDES permit for CBNG discharge in this drainage include monitoring for compliance with an EC standard and the chemical relationship between EC and SAR at designated irrigation monitoring points (IMPs). The proposed EC standard at the IMP would be equivalent to the calculated average soil EC in the irrigated fields (6.9 dS/m) divided by 1.5 to estimate the allowable salinity in the stream water. This results in a proposed EC standard of 4.6 dS/m at the IMP. The proposed EC standard of 4.6 dS/m would not be a compliance limit; instead it would represent the target water quality value that should be achieved at the IMP to protect irrigated fields.

With respect to the IMP standard for SAR, it is proposed that the WDEQ establish an appropriate monitoring program to determine whether or not effluent from the discharge facilities conforms to the following equation for SAR:

$$SAR < (7.10 \times EC) - 2.48$$

This equation applies the soil-water chemical relationship between EC and SAR and is used to evaluate whether or not the long-term use of an irrigation water source would result in potential soil structural impacts and reductions in the infiltration rate of applied water. For any measured water EC value, the equation is used to calculate a corresponding maximum SAR value that would remain within the “no reduction in rate of infiltration” zone on Figure 1 of Hanson et al. (1999). For the Dry Fork drainage, the maximum SAR standard in a water sample from the IMP would be based on the measured EC in the same sample. For example, if the EC in a water sample collected at an IMP was measured to be 3.0 dS/m, then, based on the equation above, the measured SAR in the same sample would need to be less than 18.8. In this example, the EC standard would be achieved since an EC of 3.0 dS/m is less than the proposed standard of 5.3 dS/m. The ongoing monitoring of EC and SAR at the IMP in this fashion would be used to evaluate the actual water quality that may be applied to downstream fields.

In summary, based on the analyses described herein, the discharge of CBNG produced water to the Dry Fork watershed in accordance with the proposed effluent limits and IMP standards described above is not expected to result in a measurable decrease in crop or livestock production, and would therefore be compliant with Chapter 1, Section 20 of the Wyoming Water Quality Rules and Regulations.

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TABLES

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Table 1. Soil physical analysis results for the Dry Fork project area.[1,2]

Site	Depth	Texture	Sand	Silt	Clay	Surface Clay Mineralogy[3]	Saturation Percentage	Organic Matter
	inches		%					
Field A	0-6	Sandy Clay Loam	50	26	24	Smectite 38 Illite 32 Kaolinite 30	40	2.5
	6-12	Loam	45	29	26		39	1.2
	12-24	Sandy Clay Loam	50	26	24		39	0.8
	24-36	Sandy Clay Loam	56	22	22		33	0.7
	36-48	Sandy Loam	68	18	14		23	0.4
	48-72	Sandy Loam	67	17	16		27	0.4
Field B	0-6	Silty Clay Loam	12	52	36	Smectite 40 Illite 32 Kaolinite 28	58	2.8
	6-12	Silty Clay Loam	18	48	34		53	1.8
	12-24	Silty Clay Loam	20	50	30		51	1.2
	24-36	Clay Loam	32	40	28		46	0.9
	36-48	Loam	40	34	26		41	1.0
	48-72	Sandy Clay Loam	54	25	21		37	0.7
Field D	0-6	Silty Clay Loam	8	58	34	Smectite 39 Illite 35 Kaolinite 26	73	4.0
	6-12	Silty Clay Loam	8	60	32		70	1.5
	12-24	Silty Clay	8	44	48		78	1.0
	24-36	Clay	22	34	44		65	0.8
	36-48	Clay Loam	31	31	38		54	0.6
	48-72	Clay Loam	26	38	36		54	0.8

Notes:

1. Samples were collected on July 11, 2007 at Field A and on July 12, 2007 at Field B and Field D by KC Harvey, Inc. using a Giddings Probe. Samples were analyzed by Energy Laboratories, Inc., Helena, Montana.
2. Abbreviations used are as follow: % = percent.
3. Surface clay mineralogy was determined for the 0 to 6 inch sample only. X-ray diffraction (XRD) analysis was completed by DCM Science Laboratory, Inc., Wheat Ridge, Colorado on August 1, 2007.

Table 2. Soil chemical analysis results for the Dry Fork project area.[1,2]

Site	Depth	pH	Electrical Conductivity at 25º C (EC)	Average EC to a Depth of 48 inches[3]	Calcium	Magnesium	Sodium	Sodium Adsorption Ratio (SAR)	Cation Exchange Capacity (CEC)	Exchangeable Sodium	Exchangeable Sodium Percentage (ESP)	Average ESP to a Depth of 48 inches[3]	Lime as $CaCO_3$
	inches	s.u.	dS/m		meq/L				meq/100 g		%		
Field A	0-6	6.7	3.3	7.9	22.6	7.5	5.8	1.5	21.3	0.84	2.9	16.8	1.1
	6-12	7.3	5.8		23.4	9.2	32.3	8.0	21.5	3.22	9.1		1.6
	12-24	7.9	10.5		21.9	18.2	75.8	17.0	18.9	6.99	21.0		1.3
	24-36	8.0	9.2		19.5	18.1	69.1	16.0	16.8	6.23	24.0		1.9
	36-48	7.8	7.4		21.1	15.9	49.7	12.0	11.4	2.98	16.0		1.4
	48-72	7.8	6.1		20.4	14.8	34.9	8.3	12.3	2.41	12.0		1.4
Field B	0-6	7.2	0.9	3.5	3.74	1.1	3.2	2.1	33.9	1.46	3.7	5.8	5.2
	6-12	7.5	1.5		6.99	2.1	4.8	2.3	34.0	1.51	3.7		5.0
	12-24	7.5	3.6		18.8	5.6	14.6	4.2	31.3	2.49	5.6		5.0
	24-36	7.6	3.9		20.9	7.2	16.1	4.3	26.7	2.18	5.4		4.6
	36-48	7.6	5.4		21.4	9.8	28.9	7.3	23.4	3.18	8.5		4.1
	48-72	7.7	6.1		18.8	13.5	40.1	10.0	17.3	3.68	13.0		4.8
Field D	0-6	7.3	6.5	9.2	18.0	10.7	44.0	12.0	40.3	9	14.0	22.1	4.8
	6-12	7.9	9.0		15.8	16.2	69.4	17.0	33.0	14.4	29.0		5.2
	12-24	8.1	14.3		18.8	31.1	114.0	23.0	30.4	18.1	30.0		4.9
	24-36	8.0	8.3		16.6	18.7	61.9	15.0	32.2	11.6	24.0		4.8
	36-48	7.8	6.5		18.9	16.0	40.5	9.7	27.8	5.89	13.0		7.7
	48-72	7.8	6.2		19.3	14.7	37.6	9.1	30.0	5.58	12.0		4.4
			Average EC:	**6.9**							**Average ESP:**	**13.1**	
		Confidence Interval (+/-):		**2.3**									

Notes:

1. Samples were collected on July 11, 2007 at Field A and on July 12, 2007 at Field B and Field D by KC Harvey, Inc. using a Giddings Probe. Samples were analyzed by Energy Laboratories, Inc., Helena, Montana.
2. pH, EC, calcium, magnesium, and sodium analyses were conducted using a saturated paste extract. Abbreviations used are as follows: s.u. = standard units; dS/m = deciSiemens per meter; meq/100 g = milliequivalents per 100 grams of soil, and % = percent.
3. Average EC and ESP to a depth of 48 inches was calculated by averaging the 0 to 6 and 6 to 12 inch depths to derive a 0 to 12 inch value, then averaging together each 12 inch depth increment to a depth of 48 inches.

Table 3. Livestock watering criteria and expected CBNG produced water quality in the Dry Fork project area.[1]

Analyte	Units	Livestock Watering Criteria[2]	Outfall WY0051918 003	Outfall WY0051918 005	Outfall WY0051918 006	Outfall WY0051241 031	Outfall WY0051241 035	Outfall WY0051241 036	Outfall WY0051241 040	Outfall WY0054411 -007	Outfall WY0054411 -012	Outfall WY0054411 -014	Outfall WY0054411 -010	Outfall WY0051241 -075	Expected CBNG Produced Water Quality		
															Minimum	Maximum	Average[3]
pH	*s.u.*	6.5 to 9	7.5	7.4	7.8	7.1	8.0	7.3	8.2	7.4	7.7	7.4	7.9	7.4	7.1	8.2	7.4
Electrical Conductivity (EC)	*dS/m*	7.5	2.3	3.4	2.0	2.2	1.4	1.5	1.7	2.1	3.1	1.8	1.1	1.3	1.1	3.4	1.9
Total Dissolved Solids (TDS)	*mg/L*	5000	1400	2130	1240	1320	856	895	1050	1240	1990	1060	668	761	668	2130	1150
Sodium Adsorption Ratio (SAR)		-	13.9	22.3	10.4	9.6	6.5	7.3	7.8	9.7	21.7	7.6	8.4	7.5	6.5	22.3	9.0
Anions																	
Bicarbonate	*mg/L*	-	1640	2510	1500	1540	990	1000	1230	1450	2310	1270	773	884	773	2510	1360
Chloride	*mg/L*	2000	7	12	10	12	7	6	6	7	10	7	6	7	6	12	7
Sulfate	*mg/L*	3000	<1	5	1	2	2	<1	<1	<1	<1	<1	<1	<1	1	5	2
Cations																	
Calcium	*mg/L*	-	31	38	43	63	42	42	53	52	51	55	22	35	22	63	43
Magnesium	*mg/L*	-	32	40	38	39	32	32	43	39	35	52	18	26	18	52	37
Sodium	*mg/L*	-	464	825	389	395	269	259	297	380	824	327	219	248	219	825	354
Metals[7]																	
Arsenic	*µg/L*	20	2.4	5.7	4.1	3.4	2.2	3.0	1.7	3.3	4.5	2.0	7.9	4.1	1.7	7.9	3.4
Cadmium	*µg/L*	50	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Copper	*µg/L*	500	2	1	<1	2	<1	<1	<1	1	39	<1	1	1	1	39	1
Lead	*µg/L*	100	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Mercury	*µg/L*	10	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Selenium	*µg/L*	50	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Zinc	*µg/L*	2500	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10

Notes:

1 Abbreviations used are as follows: s.u. = standard units; dS/m = deciSiemens per meter; mg/L = milligrams per liter; µg/L = micrograms per liter; and, nd = analyte not detected at the given reporting limit. "-" indicates the sample was not analyzed for a given paramete

2 Livestock watering criteria are from WYDEQ (2006) and National Academy of Sciences (1972 and 1974).

3 The median pH value is reported.

FIGURES

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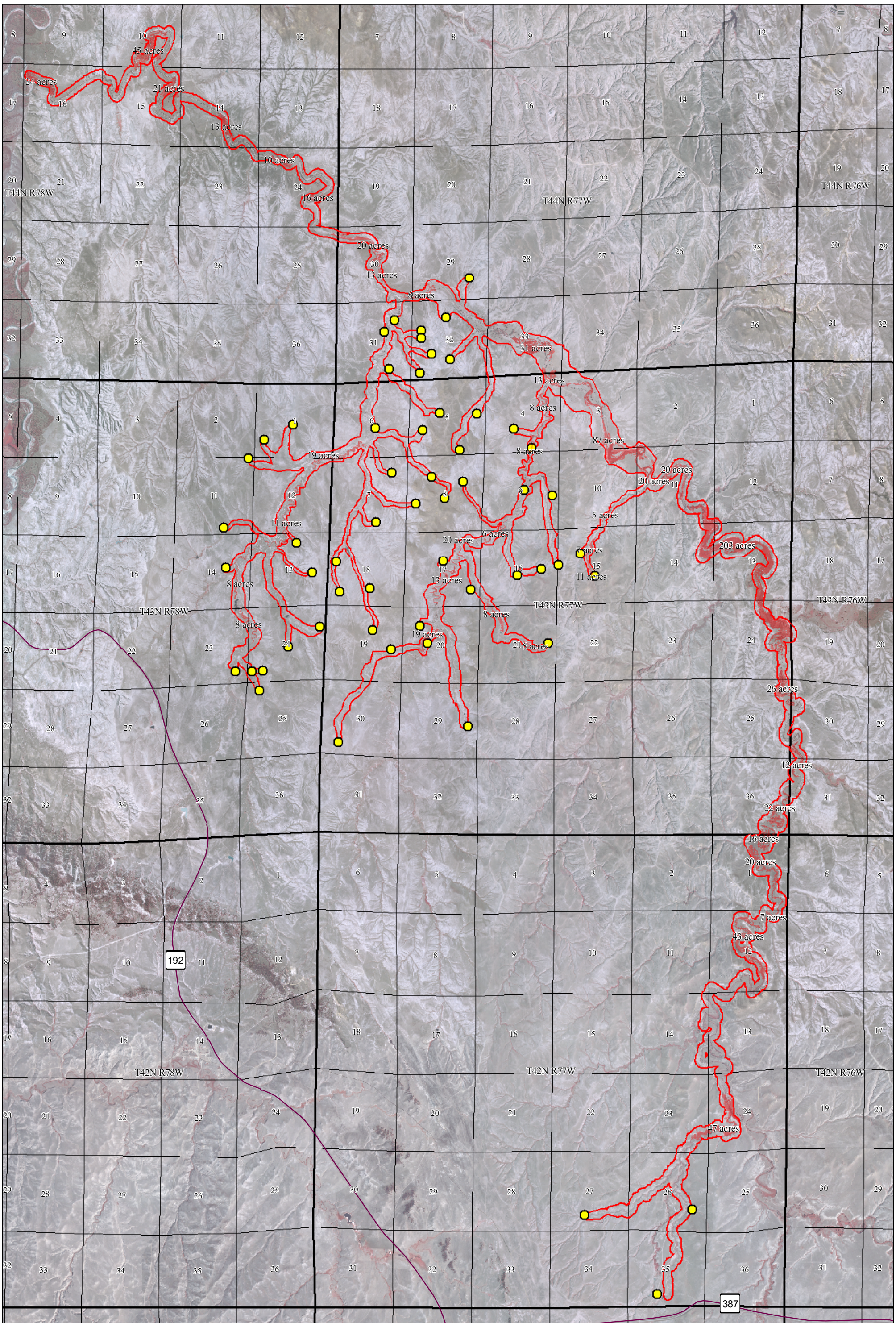

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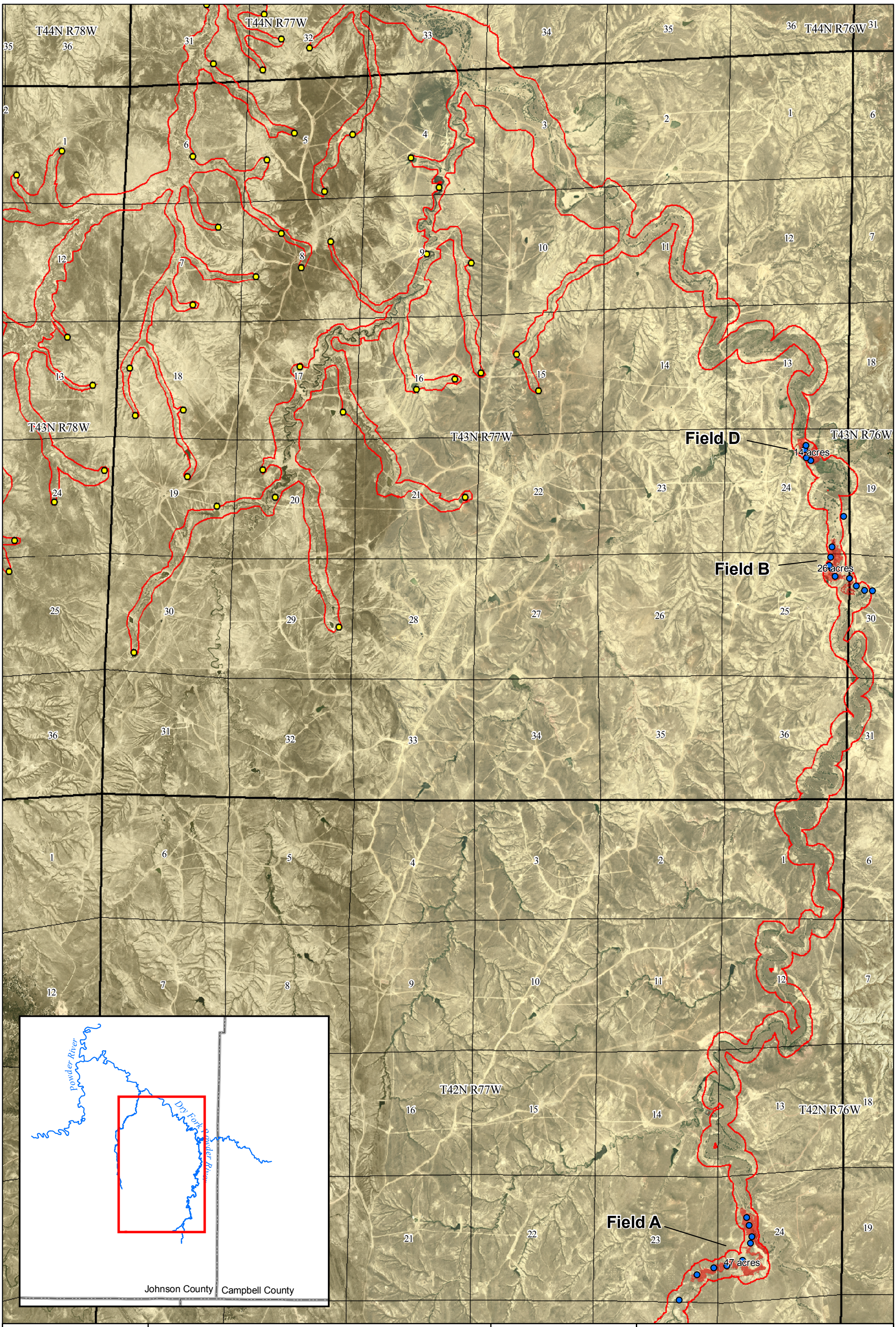
CBNG produced water outfall
Potential Naturally Subirrigated Fields
Dry Fork drainage boundary

Base imagery: 2002 Color Infra-red imagery

N
W E
S
0 1,500 3,000 6,000 Feet

Figure 1

DRY FORK POWDER RIVER SECTION 20
INFRARED AERIAL PHOTO ASSESSMENT
WITH POTENTIAL NATURALLY
SUBIRRIGATED AREAS DELINEATED



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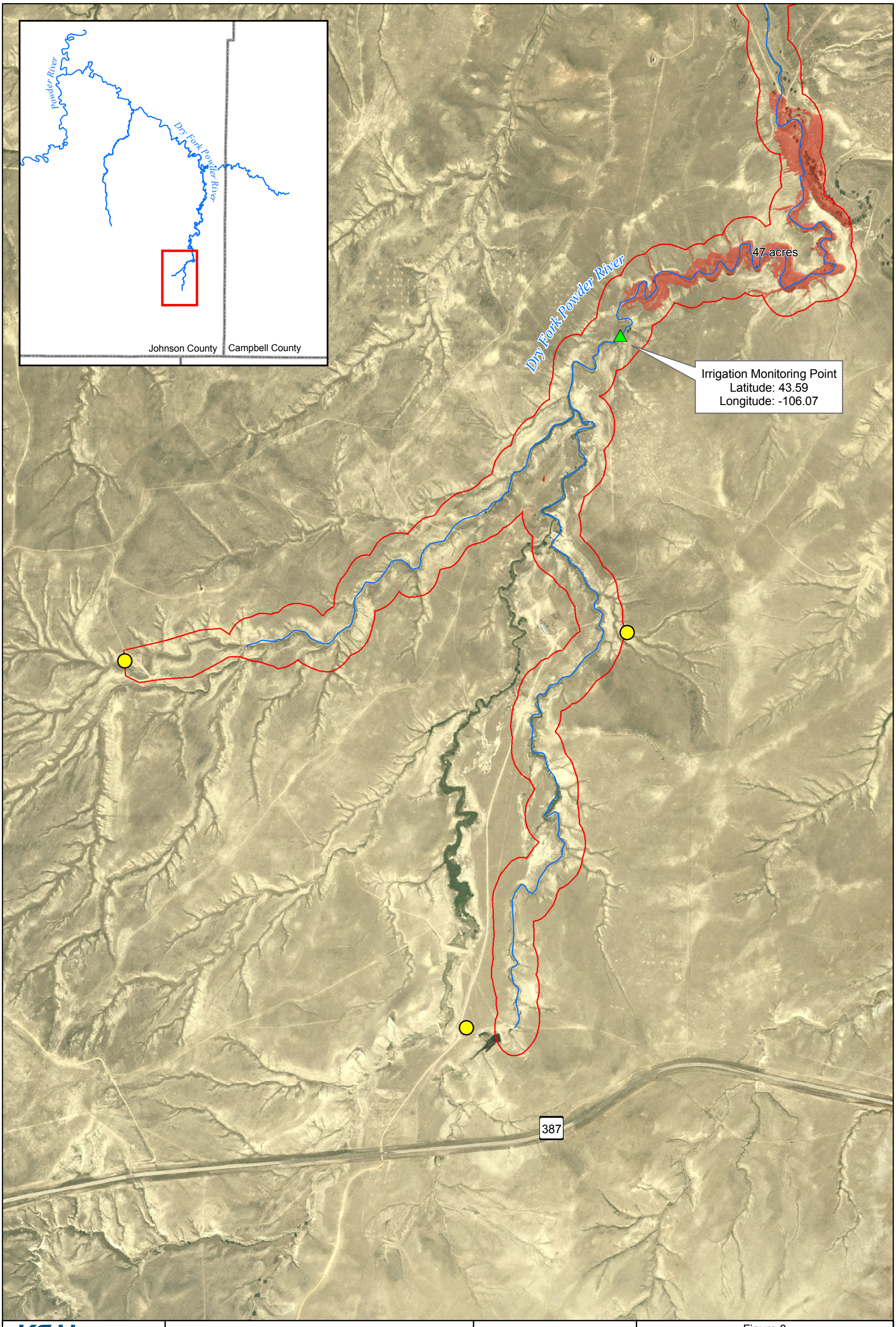
CBNG produced water outfall
Soil sample locations
Naturally subirrigated fields
Dry Fork drainage boundary

Base imagery: National Agricultural Imagery Program 2005

N W E S
0 1,300 2,600 5,200 Feet

FIGURE 2

DRY FORK POWDER RIVER SECTION 20 ASSESSMENT LOCATION OF NATURALLY SUBIRRIGATED FIELDS AND SOIL SAMPLES



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CBNG produced water outfall
Irrigation Monitoring Point
Field A
Dry Fork drainage boundary

Base imagery: National Agricultural Imagery Program 2005

N W E S
0 375 750 1,500 Feet

Figure 3

DRY FORK POWDER RIVER
SECTION 20 ASSESSMENT
LOCATION OF IRRIGATION
MONITORING POINT AND FIELD A

APPENDIX

Appendix A

ENERGY LABORATORIES, INC. • P.O. Box 5688 • 3161 East Lyndale Ave. • Helena, MT 59604
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LABORATORY ANALYTICAL REPORT

Client: Williams Production RMT
Project: Dry Fork Section 20 Analysis
Workorder: H07070150

Report Date: 08/05/07
Date Received: 07/17/07

		Analysis		pH-SatPst	COND	Percent Sat	SAR	Ca-SatPst	Mg-SatPst	Na-SatPst	K-SatPst	SO4-SatPst	Sand	Silt
		Units		s_u_	mmhos/cm	%	unitless	meq/l	meq/l	meq/l	meq/l	meq/L	%	%
Sample ID	**Client Sample ID**	**Up**	**Low**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**
H07070150-001	Field A 0-6"	0	0	6.7	3.34	40.3	1.5	22.6	7.47	5.78	1.36	25.5	50	26
H07070150-002	Field A 6-12"	0	0	7.3	5.84	39.0	8.0	23.4	9.22	32.3	0.80	54.6	45	29
H07070150-003	Field A 12-24"	0	0	7.9	10.5	38.9	17	21.9	18.2	75.8	0.61	108	50	26
H07070150-004	Field A 24-36"	0	0	8.0	9.19	32.9	16	19.5	18.1	69.1	0.45	99.3	56	22
H07070150-005	Field A 36-48"	0	0	7.8	7.35	23.1	12	21.1	15.9	49.7	0.44	80.5	68	18
H07070150-006	Field A 48-72"	0	0	7.8	6.13	27.0	8.3	20.4	14.8	34.9	0.53	67.0	67	17
H07070150-007	Field B 0-6"	0	0	7.2	0.92	57.6	2.1	3.74	1.12	3.21	0.43	3.16	12	52
H07070150-008	Field B 6-12"	0	0	7.5	1.48	52.7	2.3	6.99	2.09	4.82	0.29	10.3	18	48
H07070150-009	Field B 12-24"	0	0	7.5	3.56	51.0	4.2	18.8	5.60	14.6	0.37	31.2	20	50
H07070150-010	Field B 24-36"	0	0	7.6	3.91	46.1	4.3	20.9	7.19	16.1	0.32	39.4	32	40
H07070150-011	Field B 36-48"	0	0	7.6	5.40	41.3	7.3	21.4	9.82	28.9	0.41	51.1	40	34
H07070150-012	Field B 48-72"	0	0	7.7	6.05	36.5	10	18.8	13.5	40.1	0.47	66.1	54	25
H07070150-019	Field D 0-6"	0	0	7.3	6.50	72.8	12	18.0	10.7	44.0	0.98	60.4	8	58
H07070150-020	Field D 6-12"	0	0	7.9	8.98	69.8	17	15.8	16.2	69.4	0.53	88.8	8	60
H07070150-021	Field D 12-24"	0	0	8.1	14.3	77.5	23	18.8	31.1	114	0.76	145	8	44
H07070150-022	Field D 24-36"	0	0	8.0	8.34	65.1	15	16.6	18.7	61.9	0.53	92.1	22	34
H07070150-023	Field D 36-48"	0	0	7.8	6.47	54.2	9.7	18.9	16.0	40.5	0.55	70.4	31	31
H07070150-024	Field D 48-72"	0	0	7.8	6.23	53.7	9.1	19.3	14.7	37.6	0.51	64.9	26	38

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LABORATORY ANALYTICAL REPORT

Client: Williams Production RMT
Project: Dry Fork Section 20 Analysis
Workorder: H07070150

Report Date: 08/05/07
Date Received: 07/17/07

		Analysis		Clay	Texture	OM-WB	CEC	Lime	Na-Ext	Exch Ca	Exch Mg	Exch K	Exch Na	ESP
		Units		%	unitless	%	meq/100g	%	meq/100g	meq/100g	meq/100g	meq/100g	meq/100g	%
Sample ID	**Client Sample ID**	**Up**	**Low**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**
H07070150-001	Field A 0-6"	0	0	24	SCL	2.50	21.3	1.1	0.84	14.4	2.6	0.7	0.6	2.9
H07070150-002	Field A 6-12"	0	0	26	L	1.16	21.5	1.6	3.22				2.0	9.1
H07070150-003	Field A 12-24"	0	0	24	SCL	0.76	18.9	1.3	6.99				4.0	21
H07070150-004	Field A 24-36"	0	0	22	SCL	0.69	16.8	1.9	6.23				4.0	24
H07070150-005	Field A 36-48"	0	0	14	SL	0.35	11.4	1.4	2.98				1.8	16
H07070150-006	Field A 48-72"	0	0	16	SL	0.39	12.3	1.4	2.41				1.5	12
H07070150-007	Field B 0-6"	0	0	36	SiCL	2.81	33.9	5.2	1.46				1.3	3.7
H07070150-008	Field B 6-12"	0	0	34	SiCL	1.80	34.0	5.0	1.51				1.3	3.7
H07070150-009	Field B 12-24"	0	0	30	SiCL	1.23	31.3	5.0	2.49				1.7	5.6
H07070150-010	Field B 24-36"	0	0	28	CL	0.89	26.7	4.6	2.18				1.4	5.4
H07070150-011	Field B 36-48"	0	0	26	L	0.96	23.4	4.1	3.18				2.0	8.5
H07070150-012	Field B 48-72"	0	0	21	SCL	0.72	17.3	4.8	3.68				2.2	13
H07070150-019	Field D 0-6"	0	0	34	SiCL	3.95	40.3	4.8	9.00				5.8	14
H07070150-020	Field D 6-12"	0	0	32	SiCL	1.53	33.0	5.2	14.4				9.5	29
H07070150-021	Field D 12-24"	0	0	48	SiC	1.03	30.4	4.9	18.1				9.3	30
H07070150-022	Field D 24-36"	0	0	44	C	0.76	32.2	4.8	11.6				7.6	24
H07070150-023	Field D 36-48"	0	0	38	CL	0.62	27.8	7.7	5.89				3.7	13
H07070150-024	Field D 48-72"	0	0	36	CL	0.79	30.0	4.4	5.58				3.6	12

Appendix B

LOCATION BANKARD CO KS MT NE NM SD UT WY

Established Series
Rev. DH/PRF
04/2000

BANKARD SERIES

The Bankard series consists of very deep, well to somewhat excessively drained soils that formed in alluvium from a variety of rocks. Bankard soils are on flood plains and low terraces and have slopes of 0 to 6 percent. The mean annual precipitation is about 14 to 17 inches and the mean annual temperature is about 48 degrees F.

TAXONOMIC CLASS: Sandy, mixed, mesic Ustic Torrifluvents

TYPICAL PEDON: Bankard loamy sand - grassland. (Colors are for dry soil unless otherwise stated.)

A--0 to 5 inches; light brownish gray (2.5Y 6/2) loamy sand, grayish brown (2.5Y 5/2) moist; weak fine granular structure; soft, very friable; slightly effervescent; moderately alkaline (pH. 8.0); clear smooth boundary. (4 to 8 inches thick)

C--5 to 80 inches; light yellowish brown (2.5Y 6/3) loamy very fine sand stratified with thin layers of sand, sandy loam and loam, light olive brown (2.5Y 5/3) moist; the weighted average texture is loamy fine sand; single grain; soft, very friable, strongly effervescent; moderately alkaline (pH 8.2).

TYPE LOCATION: Morgan County, Colorado; 100 feet south and 210 feet east of the northwest corner of Sec. 30, T. 4 N., R. 56 W.

RANGE IN CHARACTERISTICS:
Depth to carbonates: 0 to 8 inches
Mean annual soil temperature: 47 to 53 degrees F.
Mean annual summer soil temperature: 60 to 78 degrees F.
Moisture control section: moist in some or all parts for as long as 60 consecutive days when the soil temperature at 20 inches is 41 degrees F., which occurs in April
Organic carbon: decreases irregularly with depth
Particle size control section: loamy fine sand predominates above 40 inches - variable in texture due to stratification
Rock fragments: 0 to 25 percent by volume - typically less than 5 percent
Comments: Some pedons have weak accumulations of secondary carbonates as soft concretions or seams. Some pedons have 0 to 35 percent gravel by volume, below 40 inches.

A horizon:
Hue: 2.5Y, 10YR, 7.5YR, 5YR
Value: 5 to 6 dry, 3 to 5 moist
Chroma: 2 to 6
Consistence: soft to slightly hard
Organic carbon: .5 to 1.5 percent
Reaction: slightly to moderately alkaline

Structure: granular to crumb, subangular blocky allowed
Texture: loamy sand

C horizon:
Hue: 2.5Y, 10YR, 7.5YR, 5YR
Value: 5 to 7 dry, 4 to 6 moist
Chroma: 2 to 4
Calcium carbonate equivalent: less than 1 to 10 percent
Reaction: slightly to strongly alkaline
Texture: loamy very fine sand stratified with thin layers of sand, sandy loam, loam
Comments: There is no distinct continuous horizon of calcium carbonate accumulation.

COMPETING SERIES:
Chupe (T): are dry in some part of the soil moisture control section in late spring and early summer
Draknab (WY): are never moist in some or all parts for as long as 60 consecutive days when the soil at 20 inches is 41 degrees or more
Ellicott (CO): are noncalcareous, contain a high proportion of medium and coarse angular granite sand and fine and very fine angular granitic gravel
Escavada (NM): are driest from April through June
Kwakina (NM)(T): are driest from April through June

GEOGRAPHIC SETTING:
Landscape: river valleys
Landform: flood plains, low terraces
Slopes: 0 to 6 percent
Elevation: 2500 to 5900 feet
Parent material: stratified, calcareous, coarse-textured, recent alluvium
Mean annual air temperature: 47 to 55 degrees F.
Mean annual precipitation: 10 to 17 inches - peak periods in spring and early summer
Frost-free period: 95 to 160 days

GEOGRAPHICALLY ASSOCIATED SOILS:
Craft: have a coarse-silty control section
Glenberg: have a coarse-loamy control section
Haverson: have a fine-loamy control section

DRAINAGE AND PERMEABILITY: Well to somewhat excessively drained; low to very low runoff; rapid to very rapid permeability.

USE AND VEGETATION: These soils are used chiefly as native pastureland; however, they are tilled in some localities. Native vegetation consists of scattered cottonwood, grass and brush.

DISTRIBUTION AND EXTENT: The floodplains and low terraces of the major streams and rivers in Colorado, Kansas, Wyoming, New Mexico and parts of South Dakota, Nebraska and eastern Utah.

MLRA OFFICE RESPONSIBLE: Salina, Kansas

SERIES ESTABLISHED: Red Willow County, Nebraska, 1965.

REMARKS: Last updated by state 2/94.

ADDITIONAL DATA:
T: 5
K: .17
WEG: 1
WEI: 220

National Cooperative Soil Survey
U.S.A.

LOCATION KIM CO+KS MT NM WY

Established Series
Rev. AJC/GB/PRF
01/2000

KIM SERIES

The Kim series consists of very deep, moderately permeable, well drained soils that formed in alluvium and mixed eolian and alluvial material derived from sandstone and shale. Kim soils are on alluvial fans below escarpments of sedimentary rock and uplands. Slopes are 0 to 20 percent. The mean annual precipitation is about 13 inches and the mean annual temperature is about 51 degrees F.

TAXONOMIC CLASS: Fine-loamy, mixed, active, calcareous, mesic Ustic Torriorthents

TYPICAL PEDON: Kim loam - grassland. (Colors are for dry soil unless otherwise noted.)

A--0 to 6 inches; grayish brown (10YR 5/2) loam, dark grayish brown (10YR 4/2) moist; moderate very fine granular structure; soft, very friable; strongly effervescent; moderately alkaline (pH 8.0); clear smooth boundary. (4 to 8 inches thick)

AC--6 to 14 inches; grayish brown (10YR 5/2) clay loam, dark grayish brown (10YR 4/2) moist; weak medium prismatic structure parting to weak medium subangular blocky; hard, very friable, plastic; violently effervescent; moderately alkaline (pH 8.0); clear wavy boundary. (6 to 10 inches thick)

C--14 to 60 inches; pale brown (10YR 6/3) clay loam, brown (10YR 5/3) moist; massive; hard, very friable; 5 percent sandstone fragments; some visible calcium carbonate occurring as small soft masses; violently effervescent; moderately alkaline (pH 8.0).

TYPE LOCATION: Bent County, Colorado; 50 feet west and .85 mile south of the northwest corner of Sec. 3, T. 26 S., R. 52 W.

RANGE IN CHARACTERISTICS: Mean annual soil temperature ranges from 49 to 58 degrees F., and mean summer soil temperature ranges from 59 to 78 degrees F. The surface 15 inches has approximately .8 percent organic matter and the sand/clay ratio ranges from 1 to about 3. The particle-size control section is typically loam, sandy clay loam, or light clay loam, and less commonly in the lower part a fine sandy loam. It has 18 to 35 percent clay, 20 to 55 percent silt, and 15 to 60 percent sand, with more than 15 percent but less than 45 percent being fine or coarser sand. Rock fragments are typically less than 10 percent and range from 0 to 15 percent. Exchangeable sodium percentage is usually less than 3 and is less than 15 in any layer as thick as 4 inches. This soil is not dry in all parts of the moisture control section for more than one-half the time that the soil temperature is above 41 degrees F. (225 to 235 days) and is not dry for 45 consecutive days following July 15.

A horizon
Hue: 5Y through 7.5YR
Value: 5 through 7 dry, 3 through 6 moist
Chroma: 2 through 4
Structure: granular structure, but has subangular blocky structure in some pedons.

Consistence: soft to slightly hard
Carbonates: In some pedons it is leached to depths of 2 to 8 inches.
Reaction: slightly alkaline or moderately alkaline (pH 7.6 to 8.2)
When the surface horizons have value as dark as 5 dry and 3 moist they contain less than 1 percent organic carbon, or they are thin enough that if mixed to depth of 7 inches the soil has an ochric epipedon.

C horizon:
Hue: 5Y through 7.5YR
Value: 6 or 7 dry, 4 through 6 moist
Chroma: 2 through 6
Reaction: moderately to strongly alkaline (pH 8.0 to 8.6)
Calcium carbonate equivalent: 1 to 14 percent
Calcium carbonate: soft masses occurs at any depths in this horizon, but it should not be concentrated into a consistent horizon of secondary carbonate accumulation.

COMPETING SERIES: These are the El Rancho, Kishona, Mikim, Neville, Paradox, Pojoaque, Shavano, Sixmile, Thedalund, Theedle, and (T) Tsosie series. Shavano, Sixmile, Thedalund, and Theedle soils have bedrock at some point above a depth of 40 inches. El Rancho, Neville, and Pojoaque soils have hue of 5YR or redder. Kishona soils have cooler annual soil temperature and have moisture control sections that are dry more than one-half the time, cumulative, that the soil temperature at 20 inches is above 41 degrees F. Kishona soils are also dry in all parts of the moisture control section for at least 60 consecutive days following July 16. Mikim and Paradox soils are dry in some parts of the moisture control section for 15 consecutive days from May 15 to July 15 when the soil temperature at 20 inches is greater than 41 degrees F. In addition, Paradox soils have hues of 5YR and redder. Tsosie soils are dry in all parts of the soil moisture control section from April 15 to July 1.

GEOGRAPHIC SETTING:
Slope: 0 to 20 percent
Landform: alluvial fans usually below escarpments of sedimentary rock
Landscape: uplands
Parent material: parent sediments derived from a variety of rocks, including sandstone, shale, and similar materials.
Mean annual precipitation: 11 to 14 inches, with peak periods of precipitation occurring during the spring and early summer.
Mean annual temperature: 47 to 53 degrees F.
Mean annual summer temperature is 74 degrees F.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Shingle soils and the competing Thedalund soils. The three series often form a toposequence. Shingle soils have bedrock at depths of 10 to 20 inches.

DRAINAGE AND PERMEABILITY:
Drainage: Well
Runoff: low to high
Premeability: moderate

USE AND VEGETATION: These soils are used principally as native pastureland; however, they are used as dry or irrigated cropland in some localities. Native vegetation typically consists of short grasses, of which blue grama predominates.

DISTRIBUTION AND EXTENT: Eastern Colorado, southeastern Wyoming, and northeastern New Mexico in MLRA 69. The series is of moderate extent.

MLRA OFFICE RESPONSIBLE: Salina, Kansas

SERIES ESTABLISHED: Big Horn County (Big Horn Area), Montana, 1970.

REMARKS: Diagnostic features include an ochric epipedon and free lime carbonate at 7 to 20 inches.
Last updated by the state 2/94.
Updated by the MLRA Office-5 on 1/12/2000 to update the parent mateials in the first paragraph and to move to a semi-tab format.

National Cooperative Soil Survey
U.S.A.

LOCATION HAVERSON CO+MT NE NM SD UT WY

Established Series
AJC/JEB/CJH
12/2002

HAVERSON SERIES

The Haverson series consists of very deep, well drained soils that formed in alluvium from mixed sources. Haverson soils are on floodplains and low terraces and have slopes of 0 to 9 percent. The mean annual precipitation is about 15 inches and the mean annual air temperature is about 49 degrees F.

TAXONOMIC CLASS: Fine-loamy, mixed, superactive, calcareous, mesic Aridic Ustifluvents

TYPICAL PEDON: Haverson loam - grassland. (Colors are for dry soil unless otherwise noted)

A1--0 to 3 inches; pale brown (10YR 6/3) loam, dark brown (10YR 3/3) moist; strong fine granular structure; slightly hard, very friable; violently effervescent; slightly alkaline (pH 7.8); clear smooth boundary. (2 to 6 inches thick)

A2--3 to 6 inches; pale brown (10YR 6/3) loam, dark brown (10YR 3/3) moist; weak fine and medium granular structure; hard, friable; strongly effervescent; slightly alkaline (pH 7.8); abrupt smooth boundary. (2 to 6 inches thick)

A3--6 to 12 inches; light brownish gray (10YR 6/2) loam, dark grayish brown (10YR 4/2) moist; weak coarse subangular blocky structure; very hard, friable; strongly effervescent; slightly alkaline (pH 7.8); clear smooth boundary. (4 to 8 inches thick)

C1--12 to 32 inches; pale brown (10YR 6/3) very fine sandy loam that has thin strata of loam, brown (10YR 4/3) moist; massive; hard, friable; strongly effervescent; slightly alkaline (pH 7.8); gradual smooth boundary. (16 to 24 inches thick)

C2--32 to 60 inches; pale brown (10YR 6/3) loam that has thin lenses of sandy loam and very fine sandy loam, brown (10YR 4/3) moist; massive; slightly hard, very friable; few fine irregularly shaped masses and seams of lime; strongly effervescent; moderately alkaline (pH 8.4)

TYPE LOCATION: Weld County, Colorado; approximately 1,320 feet south and 1,320 feet east of the northwest corner of Sec. 36, T. 10 N., R 64 W.

RANGE IN CHARACTERISTICS: Mean annual soil temperature ranges from 47 to 55 degrees F. and mean summer soil temperature ranges from 59 to 78 degrees F. Organic carbon ranges from 0.5 to 2.0 percent in the surface horizon but decreases irregularly with depth. The particle-size control section is stratified with strata ranging from sandy loam to clay loam, but averaging approximately loam. On a weighted average basis, clay ranges from 18 to 35 percent, silt from 10 to 50 percent, and sand from 20 to 60 percent with more than 15 percent but less than 35 percent being fine or coarser sand. Rock fragments are generally less that 5 percent and range from 0 to 20 percent. Some visible calcium carbonate may occur at any depth in these soils, but it is not concentrated into any consistent horizon of accumulation. This soil is not dry in all parts of the moisture control section for more than one-half the

time the soil temperature is above 41 degrees F. (195 to 210 days) and is not dry for 45 consecutive days following July 15.

The A horizon has hue of 2.5Y or 10YR, value of 4 to 6 dry, 3 to 5 moist and chroma of 2 or 3. When the value of the surface horizon is as dark as 5 dry and 3 moist, the horizon is thin enough so that if mixed to 7 inches it is too light colored or contains too little organic carbon to qualify as a mollic epipedon or are finely stratified. The A horizon usually has granular primary structure but it has subangular blocky structure in some pedons. It is soft or slightly hard. It is neutral through moderately alkaline.

The C horizon has hue of 2.5Y, 10YR or 7.5YR, value of 5 or 6 dry, 4 or 5 moist and chroma of 2 or 3. It is slightly alkaline to very strongly alkaline. It has from less-than-one to about 15 percent calcium carbonate equivalent, which differs erratically from stratum to stratum.

COMPETING SERIES: These are the Aparejo, Hickman, Hysham, Ramper and Rockypoint series (it is assumed Hickman soils are competing pending and update of the classification). Aparejo, Hickman and Ramper soils are driest during May and June in the moisture control section. In addition Aparejo soils have hues of 5YR and redder. Hysham soils have very strongly alkaline surface horizons and typically have Bt horizons with columnar structure. Rockypoint soils are dry from July through September.

GEOGRAPHIC SETTING: The Haverson soils are on floodplains and low terraces of major rivers. Slope is 0 to 9 percent. The soils formed in highly stratified, calcareous, recent alluvium derived from mixed sources. At the type location the average annual precipitation is 14 to 18 inches with peak periods of precipitation occurring during the early spring and summer. The mean annual air temperature ranges from 47 to 52 degrees F. and the mean summer temperature is 77 degrees F. The frost-free season is 125 to 180 days.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Bankard and Glenberg soils. Bankard and Glenberg soils have less than 18 percent clay in the series control section.

DRAINAGE AND PERMEABILITY: Well drained; runoff is negligible to medium depending on slope; moderate permeability.

USE AND VEGETATION: These soils are used as native pastureland, dry farm land or irrigated cropland. Native vegetation is mixed grasses, cottonwoods and brush.

DISTRIBUTION AND EXTENT: Eastern Colorado and Wyoming, northeastern New Mexico and adjacent states. This soil is of large extent.

MLRA OFFICE RESPONSIBLE: Bismarck, North Dakota

SERIES ESTABLISHED: Prowers County, Colorado, 1965.

REMARKS: Classification was changed from Ustic Torrifluvents to Aridic Ustifluvents and the type location moved from Prowers County to Weld County, Colorado in 3/94.

National Cooperative Soil Survey
U.S.A.

LOCATION GLENBERG CO+KS MT NE NM SD UT WY

Established Series
RJL/RHM/CJH
05/2005

GLENBERG SERIES

The Glenberg series consists of very deep, well drained soils that formed in stratified calcareous alluvium from mixed sources. Glenberg soils are on flood plains and low terraces. Slopes range from 0 to 8 percent. Mean annual precipitation is about 12 inches (30 centimeters) and mean annual air temperature is about 52 degrees F (11 degreesC).

TAXONOMIC CLASS: Coarse-loamy, mixed, superactive, calcareous, mesic Ustic Torrifluvents

TYPICAL PEDON: Glenberg sandy loam - grassland. (Colors are for dry soil unless otherwise noted)

A--0 to 6 inches (0 to 15 centimeters); light brownish gray (10YR 6/2) sandy loam, dark grayish brown (10YR 4/2) moist; moderate fine granular structure; soft, very friable; moderately alkaline (pH 8.0); gradual smooth boundary. (3 to 8 inches thick, 8 to 20 centimeters)

C--6 to 60 inches (15 to 152 centimeters); light brownish gray (10YR 6/2) sandy loam stratified with thin lenses of loam and loamy sand, dark grayish brown (10YR 4/2) moist; massive; slightly hard, very friable; weak and inconsistent accumulations of secondary calcium carbonate as small concretions; moderately alkaline (pH 8.2).

TYPE LOCATION: Crowley County, Colorado; 200 feet (61 meters) south and 720 feet (219 meters) east of the N1/4 corner of Sec. 17, T. 22 S., R. 58 W.

RANGE IN CHARACTERISTICS:

The soil moisture control section is moist intermittently May through August, dry December through February; aridic moisture regime bordering on ustic.
Mean annual soil temperature: 47 to 53 degrees F (8 to 11 degrees C).
Mean summer soil temperature: 65 to 74 degrees F (18 to 23 degrees C).
Depth to calcareous material: 0 to 6 inches (0 to 15 centimeters)
Visible secondary calcium carbonate as soft concretions or thin seams occurs inconsistently at any depth.
Depth to bedrock or strongly contrasting substratums is greater than 60 inches (152 centimeters).
Organic carbon content of the surface horizon: .5 to 2.0 percent and decreases irregularly with depth.
Texture of the control section: predominantly sandy loam
Particle size control section:
Clay content: 5 to 18 percent
Silt content: 5 to 40 percent
Sand content: 50 to 75 percent with more than 35 percent fine or coarser sand.
Coarse fragments: 0 to 15 percent but are commonly less than 5 percent. Some pedons may have up to 30 percent coarse fragments in any one horizon but the weighted average of the particle-size control section is less than 15 percent.

A horizon:
Hue: 10YR or 2.5Y
Value: 4 to 7 dry, 3 to 5 moist
Chroma: of 2 to 4
Texture: fine sandy loam or sandy loam
Reaction: slightly alkaline through moderately alkaline

C horizon: (An AC horizon is present in some pedons)
Hue: 10YR or 2.5Y
Value: of 5 to 7 dry, 4 or 5 moist
Chroma: of 2 to 4
Calcium carbonate equivalent: 1 to 3 percent, but is variable from pedon to pedon and from stratum to stratum within a single pedon.
Texture: stratified loamy sand to clay loam.
Clay content: averages 5 to 18 percent
Reaction: slightly alkaline to strongly alkaline.

COMPETING SERIES: These are the Cameo (CO), Clarkelen (WY), Colorow (CO), Innacutt (NM), Kornman (CO), Radnik (AZ), Redbank (WY), and Tapicito (NM) series.
Cameo soils: are usually dry in the moisture control section more than half the time in June.
Clarkelen soils: have colder air temperatures than 52 degrees and growing seasons shorter than 130 days.
Colorow soils: are moderately well drained with redoximorphic features.
Innacutt soils: have 10 to 25 percent mica in the control section.
Kornman soils: have over-thickened, nitrogen and phosphate enriched man-made surface horizons resulting from application of silty irrigation water over long periods of time.
Redbank soils: have hue of 7.5YR or redder.
Radnik soils: have hues of 2.5YR and 5YR in the control section, are driest in the soil moisture control section in May and June and receive peak precipitation in July through September and December through February.
Tapicito soils: have a soil moisture control section that is dry in May and June.

GEOGRAPHIC SETTING:
Landform: alluvial fans, flood plains, valley floors, and low terraces
Slopes: 0 to 8 percent
Parent material: thick very strongly stratified alluvial sediments derived from mixed sources.
Elevation: 3,600 to 6,000 feet (1097 to 1828 meters)
Average annual precipitation: 10 to 14 inches (25 to 35 centimeters), with peak periods of precipitation May through August.
Average annual air temperature: 49 to 55 degrees F (9 to 13 degrees C.)
Average summer temperature: 70 to 76 degrees F (21 to 24 degrees C.).
Frost-free period: 130 to 180 days.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Bankard and Haversid soils. Bankard soils have a sand or loamy sand control section. Haversid soils have 18 to 35 percent clay in the particle-size control section.

DRAINAGE AND PERMEABILITY: Well drained. Runoff is negigible to low. Permeability is moderately rapid to rapid.

USE AND VEGETATION: These soils are used primarily as pastureland and irrigated cropland.

Native vegetation is blue grama, western wheatgrass, bluestem, cottonwood, and willows.
DISTRIBUTION AND EXTENT: eastern Colorado, northeastern New Mexico, eastern Wyoming, western Nebraska, and western Kansas. LRR G, MLRA 69; The series is of large extent.

MLRA OFFICE RESPONSIBLE: Salina, Kansas

SERIES ESTABLISHED: Red Willow County, Nebraska, 1965.

REMARKS:
Diagnostic horizons and features recognized in this pedon are:
Ochric epipedon: 0 to 6 inches (0 to 15 centimeters). (A horizon)
Fluventic materials: thin stratifications of loam to loamy sand from 6 to 60 inches (15 to 152 centimeters). (C horizon)
Aridic moisture regime bordering on ustic.
Series is updated from 7/86 to 2/94 for use on the Final Correlation of Kit Carson County, Colorado.
Opening Paragraph:
Revised MAP from 13 inches to 12 inches
RIC Section:
Ranged MAST from 47 to 59 degrees F. to 47 to 53 degrees F.
Ranged MSST from 65 to 78 degrees F. to 65 to 74 degrees F.
Competing Series:
Added and competed Radnik (WY) series
Geographic Setting:
Ranged MAP 10 to 13 inches
Adjusted MAAT 49 to 55 degrees F. and Summer Air Temperature to 76 degrees F.
Adjusted precipitation for Utah and New Mexico from 8 to 12 to 8 to 13 inches.
Distribution & Extent:
Deleted Montana as the state is all frigid.
Remarks:
Added, "Diagnostic features include a horizon of thin
stratification from 6 to 60 inches of loam and loamy
sand. Last updated by the state 2/94."
11/21/96 (redone 7/9/97)
1. Added superactive to family.
2. Ranged OC content of suface to 0.5%.
3. Allowed fine sandy loam texture in A horizon.
9/3/97 Range ppt in Nebraska to 17".
01/04/00 (A result of 12/23/99 request from Kansas MO) 1. Range A horizon thickness to 3 inches. 2. Allow value of 4 dry in the A horizon. 3. Allow chroma of 4 in C horizon. 4. Allow slightly alkaline in C horizon. 5. Minor editorial changes.
3/28/2003
1. Update associated soils section. 2. Add soil moisture control section statement to RIC 3. Allow for presence of AC horizon. 4. Range carbonates from 0-6 inches. 5. Range organic carbon in A horizon to 2%. 6. Range precipitation from 10 to 14 inches. 7. Range elevation from 3600 to 6000. 8. Range frost free period from 130 to 180 days. 9. Range MSST from 70 to 76 10. Update competing series section. 11. Leave in ranges for specific states.
3/22/04 Transfer responsibility to Kansas MO.
4/2004 WAW Convert to semi-tabular format.
Taxonomic Version: Second Edition, 1999.

National Cooperative Soil Survey
U.S.A.

Appendix C

Appendix B. Vegetation canopy cover by species based on transect data

Field A	
Alyssum species	0.10%
American licorice	1.33%
Baltic rush	0.37%
Black medick	0.07%
Common pepperweed	6.73%
Crested wheatgrass	0.63%
Curleycup gumweed	0.87%
Dandelion	0.27%
Erect knotweed	0.10%
Field brome	7.43%
Field horsetail	2.63%
Foxtail barley	0.73%
Fringed sagewort	0.43%
Kentucky bluegrass	1.50%
Lemon scurfpea	0.03%
Native aster species	0.80%
Prairie cordgrass	2.00%
Prickly lettuce	0.20%
Redroot pigweed	0.07%
Salsify	0.47%
Saltgrass	10.37%
Sandberg bluegrass	0.83%
Sedge species	0.23%
Slender wheatgrass	0.27%
Twogrooved milkvetch	0.07%
Western wheatgrass	22.20%
Western yarrow	1.33%
White sagebrush	0.10%
Woolly plantain	0.20%
Yellow sweetclover	8.37%
Litter	6.57%
Bare Ground	22.70%

Field B	
American vetch	0.50%
Common pepperweed	0.10%
Crested wheatgrass	15.10%
Dandelion	0.40%
Erect knotweed	0.10%
Field brome	6.90%
Field pennycress	0.40%
Green needlegrass	0.30%
Kentucky bluegrass	0.20%
Lambsquarters	11.80%
Nuttall's povertyweed	0.80%
Sheperd's purse	0.10%
Smooth Brome	12.00%
Western panicgrass	0.70%
Western wheatgrass	13.70%
Wheat	0.20%
Yellow sweetclover	0.90%
Litter	5.80%
Bare ground	30.00%

Field D	
Crested wheatgrass	9.80%
Foxtail barley	0.50%
Lambsquarters	13.80%
Sandberg bluegrass	3.70%
Showy milkweed	0.50%
Smooth Brome	2.50%
Thistle species	0.90%
Twogrooved milkvetch	0.70%
Unknown weedy forb	26.80%
Western tansymustard	0.40%
Western wheatgrass	22.20%
Litter	4.30%
Bare ground	13.90%