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SECTION 20 COMPLIANCE ANALYSIS FOR PROPOSED CBNG PRODUCED WATER DISCHARGES BY YATES PETROLEUM CORPORATION, DEVON ENERGY CORPORATION, AND BILL BARRETT CORPORATION TO COTTONWOOD CREEK, CAMPBELL AND JOHNSON COUNTY, WYOMING

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EXECUTIVE SUMMARY

This report presents an assessment of the potential impacts to downstream agricultural uses on Cottonwood Creek from the proposed discharge of produced water to Cottonwood Creek in Campbell and Johnson County, Wyoming. The discharge of produced water will be from three producers, Yates Petroleum Corporation (Yates), Devon Energy Corporation (Devon) and Bill Barrett Corporation (Barrett). Yates, Devon, and Barrett are jointly submitting this Cottonwood Creek Section 20 Analysis Report. The water management strategy proposed by Yates, Devon and Barrett for the Cottonwood Creek CBNG Project is for storage in on-channel reservoirs with releases to Cottonwood Creek 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 be in compliance with Chapter 1, Section 20 of the Wyoming Water Quality Rules and Regulations. A Tier 2 – Background Water Quality Analysis will be conducted to recommend EC and SAR effluent limits that will cause no harm to the existing irrigation uses. A field investigation was conducted on the T-Chair Land Company; seven fields adjacent to Cottonwood Creek were sampled.

Soil sampling in the Cottonwood Creek 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 measured in the Cottonwood Creek fields with the expected CBNG produced water quality water reveals that no decreases in agricultural production will result. The CBNG produced water from the Cottonwood Creek project area has an EC that ranges from 1.3 to 2.3 dS/m and an SAR from 6.1 to 8.6. The estimated historic water quality of Cottonwood Creek has an EC of 2.8 dS/m. Average EC values in the T-Chair Land Company fields, to a depth of 48 inches, range from 1.5 to 6.2 dS/m. Average ESP levels, to a depth of 48 inches, in the Cottonwood Creek fields range from 2.9 to 22 percent.

Based on the analysis presented herein, effluent limits that will cause no harm to existing agricultural uses on Cottonwood Creek are an EC of 2.8 dS/m and an SAR of 17. At these effluent limits, any discharge into Cottonwood Creek or its tributaries by Yates, Devon and Barrett will not result in a measurable decrease in crop or livestock production.

1.0 INTRODUCTION

This report presents an assessment of the potential impacts to downstream agricultural uses on Cottonwood Creek from the proposed discharge of coalbed natural gas (CBNG) produced water to Cottonwood Creek and its tributaries in Campbell and Johnson County, Wyoming. The discharge of produced water will be from Yates Petroleum Corporation (Yates), Devon Energy Corporation (Devon) and Bill Barrett Corporation (Barrett). Yates, Devon, and Barrett are jointly submitting this report. The purpose of this evaluation is to demonstrate whether the proposed discharges will be in 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.*

This report includes an evaluation of land owned by Patricia Clark of the T-Chair Land Company, including a naturally irrigated field and a series of irrigated spreader-dike fields (Figure 1). According to research conducted by Yates, Devon, and Barrett, other naturally irrigated fields exist on the Dry Fork Powder River downstream of the proposed discharges. However the naturally irrigated fields along the Dry Fork Powder River were not sampled as part of this investigation because discharge of CBNG water has previously occurred in the Dry Fork Powder River basin. Therefore, the Cottonwood Creek fields were considered to be most representative of baseline conditions and the most sensitive to potential effects associated with the discharge of produced water immediately upstream in the Cottonwood Creek watershed.

The analysis presented herein will demonstrate whether or not any discharge made by Yates, Devon and Barrett into Cottonwood Creek and its tributaries will result in a measurable decrease in crop or livestock production. To accomplish this, soil scientists from KC Harvey, Inc. conducted a site investigation of the fields adjacent to Cottonwood Creek on the T-Chair Land Company property that included soil sampling and analysis. These data, along with data regarding proposed discharge water quality, vegetation types, irrigation conditions, water management strategies, etc., were used to evaluate whether or not there would be a measureable decrease in crop and/or livestock production downstream of the proposed discharges to the Cottonwood Creek watershed.

Regulatory guidance for conducting the following Section 20 analysis is based on the information requirements stipulated in Item 23 of the Wyoming DEQ WYPDES Application for Permit to Surface Discharge Produced Water from Coal Bed Methane New Discharges, Renewals, or Major Modifications, revised June 22, 2006, and the current draft Section 20

Agricultural Use Protection Policy, dated December 2006 (WYDEQ, 2006). Using a Tier 2 – Background Water Quality Analysis approach, this report will recommend EC and SAR effluent limits that will cause no harm to the existing irrigation uses.

The main body of this report is comprised of six sections, including this introduction (Section 1). Section 2 describes the baseline hydrologic, soil and vegetation conditions that are representative of naturally and passively irrigated soils in the Cottonwood Creek watershed. Information on the proposed CBNG discharges is provided in Section 3, including Yates, Devon and Barrett's water management strategies, the location of proposed discharges, and the expected produced water quality. Section 4 will provide a prediction of the long-term average water quality in Cottonwood Creek and an assessment of the potential impacts the proposed discharges will have on soils, vegetation, and livestock. Lastly, effluent limits that are protective of the downstream irrigation uses and a summary regarding compliance with the Section 20 narrative standard will be presented in Section 5. References cited throughout the report are provided in Section 6. Tables, figures, and appendices are located at the end of this report.

2.0 BASELINE CONDITIONS

2.1 Hydrologic Conditions

2.1.1 Hydrology and Irrigation Uses

The proposed CBNG produced water discharges will occur to Cottonwood Creek and its tributaries. Cottonwood Creek drains an 80 square mile watershed that straddles the Campbell and Johnson County lines. Cottonwood Creek flows west-northwest to the Dry Fork Powder River, which drains to the Powder River. Cottonwood Creek and its tributaries are considered ephemeral; natural flow occurs periodically in response to rainfall and snowmelt events.

According to a search of the Wyoming State Engineer's Office water rights database, there is one permitted irrigation diversion on Cottonwood Creek. The permit is held by Patricia Clark of the T-Chair Land Company. A spreader dike system with 55 earthen dikes has been installed on Cottonwood Creek; construction of the spreader dike system occurred over 70 years, starting in the 1920's and continuing through the 1990's (Clark, 2006). The spreader dike system begins at the confluence of Cottonwood Creek and Collins Draw; the confluence lies in the northwest quarter of Section 26, Township 43 North, Range 76 West. For the purposes of this report the irrigated areas associated with the 55 spreader dikes were grouped into six fields, labeled as Fields 2 through 7 on Figure 2 and Figure 3. Fields 2 through 7 were each associated with a series of spreader dikes based on topography and NRCS mapped soil series, and encompass approximately 263 acres (Table 1). Field 1 is a naturally irrigated field along Cottonwood Creek on the T-Chair Land Company property immediately upstream of the spreader dike system (Table 1 and Figure 2). For the purposes of this report, downstream agricultural use consists of natural irrigation, passive irrigation through periodic flooding of the spreader dike system during run off events, and livestock water use.

2.1.2 Surface Water Quality

Historic water quality data are not available in the Cottonwood Creek drainage or other analog drainages. An exhaustive search of several databases, including the United States Geologic Survey database and the Wyoming Department of Environmental Quality website was completed.

2.2 Soil Conditions

Seven contiguous fields along Cottonwood Creek were investigated to document current soil conditions (Figure 2 and Figure 3). In Fields 2 through 7, soil sampling occurred adjacent to and in between the spreader dikes. The fields are located in sections 19, 20, 21, 22, 26 and 36 of Township 43 North, Range 76 West in Campbell and Johnson County, Wyoming.

2.2.1 NRCS Soil Mapping Units

Soils bordering the entire length of Cottonwood Creek have been mapped in the Campbell and Johnson County soil surveys (Figure 4 and Figure 5). The portion of Cottonwood Creek in Campbell County has been mapped as a Clarkelen-Keeline association, 0 to 6 percent slopes, and as a Haverdad-Clarkelen complex, 0 to 4 percent slopes (Figure 4 and Figure 5). The lower reach of Cottonwood Creek, found in Johnson County has been mapped as a Haverson-Glenberg association (Figure 5). The official NRCS descriptions for the Clarkelen, Keeline, Haverdad, Haverson and Glenberg soil series are included in Appendix A.

Clarkelen soils are very deep, well, moderately well or somewhat excessively drained soils that formed in stratified recent stream alluvium from mixed sources on flood plains and terraces. Permeability is moderately rapid. Textures range from fine sandy loam to loam, with clay fractions ranging from 5 to 18 percent. The subsurface horizon soil EC levels are typically less than 4 dS/m, but may range up to 8 dS/m when irrigated or where it receives saline discharges from surrounding shale beds. Clarkelen soils receive an average of 12 inches of precipitation annually, over half of which falls as rain or snow from April through June. Clarkelen soils are primarily used as rangeland. Native vegetation consists of needleandthread, western wheatgrass, and silver sagebrush with scattered stands of cottonwoods (National Cooperative Soil Survey, 2005a).

Keeline soils are described as very deep, well or somewhat excessively drained soils formed in alluvium or eolian deposits derived from sandstone on upland ridges hillslopes, terraces, benches, alluvial fans, and fan remnants. Textures range from fine sandy loam to sandy loam, with clay fractions ranging from 5 to 18 percent. Permeability is moderately rapid. Soil EC levels range from 0 to 4 dS/m throughout the profile. Keeline soils receive an average of 12 inches of precipitation per year, with over half the precipitation occurring in April, May, and June. These soils are mainly used for grazing with principal native vegetation being needleandthread, prairie sandreed, Indian ricegrass and little bluestem (National Cooperative Soil Survey, 2002c).

Haverdad soils are very deep, well-drained soils that formed in stratified alluvium on flood plains and low terraces. Textures range from sandy loam to clay loam, with clay fractions ranging from 15 to 35 percent. Haverdad soils generally have mixed clay mineralogy. Soil EC ranges from 0 to 8 dS/m throughout the profile, with EC levels as high as 16 dS/m in areas with irrigation. Haverdad soils receive an average of 11 inches of precipitation per year, with over half the precipitation occurring in April, May, and June. Permeability is moderate. Flooding on Haverdad soils occurs for brief periods during spring runoff and after thunderstorms. These soils are typicallly used for grazing with principal native vegetation being big sagebrush, western wheatgrass, greasewood, and annual grasses and forbs (National Cooperative Soil Survey, 2002a).

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 percentage typically ranges 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).

Glenberg soils are very deep, well-drained soils that weathered from stratified alluvium rich in calcareous materials from mixed sources. Glenberg soils are generally found on floodplains and low terraces. Sandy loam is the most common soil texture; 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).

2.2.2 Soil Sampling and Analysis Methods

Two soil scientists from KC Harvey, Inc. conducted a soil investigation of the seven Cottonwood Creek fields on December 5th and 6th, 2006. Five to nine sub-samples were collected in each of the seven fields along Cottonwood Creek (Table 1). Each sample location was marked using a handheld global positioning system (GPS) unit (Figure 2 and Figure 3). Soil samples were collected using a truck-mounted Giddings Probe (Giddings Machine Company, Windsor, Colorado). At each sample location, soil samples were collected from seven depth increments, 0 to 6, 6 to 12, 12 to 24, 24 to 36, 36 to 48, 48 to 72, and 72 to 96 inches. Samples were composited by depth for a total of seven samples per field. Samples were delivered under chain-of-custody to Energy Laboratories, Inc. in Helena, Montana for analysis of pH, electrical conductivity (EC), dissolved calcium, dissolved magnesium, dissolved sodium, sodium adsorption ratio (SAR), saturation percentage, exchangeable sodium, cation exchange capacity (CEC), exchangeable sodium percentage (ESP), texture (percent sand, silt, and clay), percent lime, percent organic matter (0-6 inch samples only), and clay mineralogy (0-6 inch samples only). Results of the physical and chemical soil analyses from the Cottonwood Creek fields are summarized in Table 2 and Table 3. The original laboratory reports are provided in Appendix B.

Even though the seven fields that were sampled in the Cottonwood Creek soil investigation are contiguous, the seven fields were sampled individually to better gauge the natural soil variability. The total irrigated area represented by the Cottonwood Creek soil investigation is 296 acres; one set of samples that would be representative of the entire area would be difficult to collect. However collecting soil samples from the delimited individual fields and then averaging the results yields soils information that is representative of the entire area.

2.2.3 Soil Physical Conditions

Soil physical properties affect aeration rates, water infiltration, water storage, and movement of water through the soil profile. Soil textures are clay loam, silty clay loam, silty loam, loam, sandy clay loam, and sandy loam in the soil samples from the Cottonwood Creek fields. Clay content ranges from 10 to 40 percent in all depths sampled (Table 2). Compared to other soils in the Powder River Basin, the clay contents found in the soils at the Cottonwood Creek site are considered low to moderate.

The effects associated with sodic irrigation water may depend upon the clay mineralogy of the soil. The clay mineralogy of the Cottonwood Creek surface soil samples (0 to 6 inches) was analyzed using X-ray diffraction (XRD). Smectite composes 40 to 50 percent of the clay fraction; followed closely by illite and kaolinite which range from 25 to 36 and 18 to 21 percent, respectively (Table 2). Smectitic clays are 2:1 clays that expand upon wetting and shrink after drying; the degree of swelling may increase when sodic waters are applied to such clays. Non-expanding clays, such as illite, kaolinite, and chlorite are less likely to be affected by sodic waters.

Percent organic matter in the surface soil samples (0-6 inch) ranges from 1.8 to 3.4 percent (Table 2), which is typical of these soil types in the Powder River Basin.

2.2.4 Soil Chemical Conditions

Soil pH

Soil pH is perhaps the most important chemical characteristic of the soil and indicates the intensity of the acidic or basic condition of the soil. Soil pH serves as a general index to the availability of plant nutrients, potential toxicity problems, and sodic soil conditions. A soil pH of 6.5 to 8.4 is ideal for most range plants. As the soil pH increases above or decreases below this range, the availability of phosphorus, calcium, magnesium, iron, manganese, zinc, copper, cobalt, and boron may become limiting to plants. In the Cottonwood Creek soil samples, soil pH ranges from 7.4 to 8.2 (Table 3).

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 obtain water (Bohn, et al., 1985). Saline soils are conventionally defined as having EC values of greater than 4 dS/m, however sensitive plants can be affected at 2 dS/m and more tolerant plants (e.g., many of the native species of the Powder

River Basin) are productive at EC levels greater than 8 dS/m. In the arid western United States, naturally occurring saline soils are more common because arid regions are subject to high evaporation rates, thus allowing salt concentration to occur (Soil Improvement Committee, California Plant Health Association, 2002).

Soil sample EC ranged from 0.44 to 7.4 dS/m in the 0 to 72 inch depth increments of the Cottonwood Creek fields (Table 3). These values are comparable to the values reported for the Clarkelen, Keeline and Haverdad mapped NRCS soil series.

An average soil EC was calculated to a depth of 48 inches. As specified in the Agricultural Use Protection Policy, the 48 inch depth is representative of the average root zone depth of the grass species present at the Cottonwood Creek fields. The average soil EC is reflective of the long-term application of Cottonwood Creek water and will be used to determine background water quality. The average soil EC was calculated using the following formula:

$$\text{Average Soil EC} = (((EC_{0\text{-}6} + EC_{6\text{-}12}) \div 2) + EC_{12\text{-}24} + EC_{24\text{-}36} + EC_{36\text{-}48}) \div 4$$

Where, $EC_{0\text{-}6}$ is the EC measured in the first six inches of the root zone (0 to 6 inches). Because soil samples were collected from the 0 to 6, and 6 to 12 inch increments, the EC results for the two depths were averaged together to derive the 0 to 12 inch EC value for the average soil EC calculation. The average soil EC ranged from 1.5 to 6.2 dS/m in the Cottonwood Creek fields (Table 3). Four of the seven fields sampled, (Field 3, Field 5, Field 6, and Field 7) have average soil EC values of greater than 4.0 dS/m which classifies these soils as saline (Table 3). Only plants that are tolerant or moderately tolerant of soil salinity are well suited for growth on Field 3, Field 5, Field 6, and Field 7.

Soil Sodicity

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 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).

Clay minerals are the most physically and chemically reactive components of the sand, silt, and clay fractions of the soil. Soil clay minerals 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 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 site expressed as a percent of the cation exchange capacity in milli-equivalents per 100 grams of soil (meq/100 g). Thus,

ESP = (exchangeable sodium / cation exchange capacity) x 100.

As indicated above, sodic soil conditions arise when greater than 15% of the ions bonded to the clay minerals are sodium; 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 clay minerals, resulting in soil swelling (Levy et al., 1998). This causes negative effects on the physical structure of the soil. Upon re-wetting, the clay minerals may disperse and settle into soil pores, effectively clogging the pores 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 is also important, with the expanding smectitic clays being the most problematic.

Soil ESP values range from 1.1 to 37 percent in the Cottonwood Creek soil samples (Table 3). The average soil ESP, to a depth of 48 inches, was calculated using the same approach as was used to calculate the average soil EC. The average soil ESP, to a depth of 48 inches ranges from 2.9 to 22 percent. Sodic soil conditions exist naturally in Fields 3, 5, 6, and 7; and, when combined with the measured salinity, Fields 3, 5, 6, and 7 are considered saline-sodic (Table 3). 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. Regardless of which interpretation, Fields 3, 5, 6, and 7 are naturally limited for crop production because of the enriched salinity and sodicity.

Saturation percentage is as an index of the swelling capacity and the tendency to form dispersive conditions in a soil (Merrill et al., 1987). Saturation percentage is the amount of water, by weight, necessary to form a minimally flowable paste from dry soil materials (Merrill et al., 1987) In general, a saturation percentage of less than 80% indicates the soil does not have a tendency to swell, which also reduces the tendency for dispersion. The saturation percentages measured in the Cottonwood Creek soils range from 29 to 65 percent (Table 3), which indicates non-dispersive conditions.

2.3 Vegetation Conditions

On December 5, 2006, an interview was conducted with Ms. Patricia Clark and Mr. Gene Mankin (T-Chair Land Company) to establish current agricultural practices (Clark, 2006). Reportedly, alfalfa was planted in Field 4 and Field 5; however the stand was unsuccessful because the site is "too dry." The landowners indicate that they may re-plant the area with another alfalfa cultivar in the future. Currently, native and non-native forage grasses are growing in each of the seven fields. Several species were observed during the site visit, dominant grass species include: fescue, brome, bluegrass, crested wheatgrass, cheatgrass, and prairie junegrass. Additional species were present but unidentifiable. Cottonwood stands are common near the stream channel and present in all fields. No other formal vegetation inventory was conducted on

Cottonwood Creek due to the time of year of the site investigation (December). However because a Tier 2 assessment is being performed, no other vegetation survey is required.

3.0 PROPOSED CBNG DISCHARGES

3.1 Water Management Strategy and Proposed Discharge Locations

The water management strategy proposed by Yates, Devon and Barrett for the Cottonwood Creek CBNG Project is water storage in on-channel reservoirs with release to Cottonwood Creek only when natural storm flows cause the on-channel reservoirs to overflow or when the T-Chair ranch requests the water. Reservoirs are located on tributaries to Cottonwood Creek, in Sections 18, 33, 32, 34 of Township 43 North, Range 75 West; Sections 2, 3, 4, 5, 7, 8, 9, 10, 11, 12, 14, 15, 17, 19, 20, 21, 22, 29, and 32 of Township 42 North, Range 75 West; and, Section 13, of Township 42 North, Range 76 West, of Campbell County. Yates, Devon and Barrett have submitted complete documentation and specific locations of all reservoirs and outfalls as per WYDEQ permit application requirements.

3.2 Discharge Water Quality

Expected CBNG produced water quality to be discharged to the Cottonwood Creek drainage is provided in Table 4. Water quality data are from two of Yates' existing outfalls, WY 0049352-001 and WY 0049352-002, which are located in the Cottonwood Creek drainage. Samples were collected by Yates on July 21, 2006 and September 5, 2006 (Table 4.). Devon collected a water sample from their Outfall WY 0046612; the sample was collected on September 21, 2004 (Table 4). The Barrett expected water quality sample was collected by Devon at Outfall WY 0046612 on April 17, 2006. Energy Laboratories, Inc., of Gillette, Wyoming, conducted all water quality analyses. Yates, Devon, and Barrett have indicated that these data are from wells that represent a small portion of the total project area and that the produced water quality may change as full development occurs. Currently, the expected EC of the produced water to be discharged ranges from 1.3 to 2.3 dS/m, with an SAR of 6.1 to 8.6 (Table 4).

4.0 ASSESSMENT OF POTENTIAL IMPACTS

4.1 Technical Approach

The "Tier 2 – Background Water Quality" approach included in the current draft Section 20 Agricultural Use Protection Policy (WYDEQ, 2006) is used herein to calculate the pre-existing background water quality. Because the pre-existing background water quality is worse than the effluent quality, EC and SAR limits will be based upon the background conditions. In addition, aspects of the "Tier 3 – No Harm Analysis" will be used to demonstrate that a measurable decrease in agricultural production would not be expected due to the proposed discharge of CBNG produced water by Yates, Devon, and Barrett into Cottonwood Creek. To gauge the potential impacts to soils, the EC-SAR of the expected CBNG produced water is compared to the guidelines presented in Ayers and Westcot (1985) and Hanson et al. (1999) to assess the potential sodicity risk of the produced water. To gauge the potential impacts to vegetation, the EC of the expected CBNG produced water is used to predict the average root zone soil EC of the Cottonwood Creek fields, assuming this water were used for long-term irrigation. It will be demonstrated that the predicted long-term average soil EC that will be developed in response to irrigation with CBNG produced water, is less than the current average soil EC. Finally, the potential impacts to livestock production will be assessed by comparing the CBNG produced water with livestock watering standards.

4.2 Predicted Long-term Average Water Quality

As mentioned in Section 2.1.2, historic water quality data are not available for the Cottonwood Creek drainage. Soil chemical conditions along Cottonwood Creek have developed in response to the runoff water quality supplied by Cottonwood Creek over the long term. Soil chemistry, particularly soil EC, is a function of the long-term average water quality received by the soil. The following equation is a frequently cited relationship that relates irrigated water quality to the soil EC:

$$EC_e = 1.5 \times EC_w.$$

Where EC_e is the average EC of the soil, and EC_w 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:

$$EC_w = EC_e \div 1.5$$

The resultant equation allows for the prediction of long-term average EC of the applied water, given that soil data has been collected at a specific site. With an average soil EC to a depth of 48 inches of 4.2 dS/m, the long-term average EC of Cottonwood Creek runoff water is predicted to be 2.8 dS/m.

4.3 Assessment of Potential Soil Impacts

As discussed above in Section 2.2.4, soil hydraulic properties such as infiltration and permeability can decrease if an abundance of sodium ions are adsorbed by the clay minerals in soil. Excessive adsorbed or exchangeable sodium can result from sustained application of water that is high in sodium and low in calcium and magnesium. Consequently, the ratio of sodium to calcium and magnesium ions in water is an important property affecting the infiltration and permeability hazard. The water quality index used to measure the hazard related to sodium abundance or sodicity in 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 unitless SAR value can be calculated from the sodium, calcium and magnesium concentrations via the formula:

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

where the dissolved 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. The potential for clay mineral swelling and dispersion, and a subsequent reduction in soil infiltration and permeability is a function of both EC and SAR. Therefore, in order to evaluate the sodicity risk of water, the EC of the water must be considered. To this end, the EC-SAR guidelines presented in Ayers and Westcot (1985) and Hanson et al. (1999) are used to assess the potential sodicity risk of water applied to soils. These guidelines are currently utilized by the WYDEQ to help derive SAR limits for WYPDES permits and judge compliance with the Chapter 1, Section 20 narrative standard for protection of the Agricultural Water Supply.

The paired EC-SAR values for the four different produced water samples (Table 4) were compared to the EC-SAR guidelines presented in Ayers and Westcot (1985) and Hanson et al. (1999). This assessment indicates that all four produced water samples would result in a "no reduction in infiltration" if used for long-term irrigation. In addition, the average of the four CBNG produced water EC-SAR values (Table 4) were compared to the Ayers and Westcot (1985) and Hanson et al. (1999) guidelines. The average EC-SAR values would also result in a "no reduction in infiltration" if this water was used for long-term irrigation. Based on this assessment, the water that could potentially spread over the Cottonwood Creek fields will not cause any decrease in soil hydraulic function that could lead to a measurable decrease in forage production.

Based on the average EC of the soils in the irrigated fields of Cottonwood Creek, the long-term average EC of Cottonwood Creek runoff water is predicted to be 2.8 dS/m. Water that may irrigate the Cottonwood Creek soils would be within the "no reduction in infiltration" zone indicated by Ayers and Westcot (1985) and Hanson et al. (1999) with a long-term average SAR of up to 17. It is important to note that relatively high SAR water has likely irrigated the Cottonwood Creek fields in the past given that the average ESP to a depth of 48 inches is 12.6 percent (Table 3).

4.4 Assessment of Potential Vegetation Impacts

4.4.1 Salinity

As discussed above, salts make it more difficult for plants to extract water from the soil and are a concern if the crop yield is affected. 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). Plant species vary with respect to salt tolerance. Plant growth responds to the average root zone EC of the soil. Soil EC can be altered by the EC of applied water during long-term use of the water.

In order for there to be a measurable decrease in forage production on the Cottonwood Creek fields due to soil salinity, the average root zone EC of the fields must be increased beyond the current baseline level (this conservatively assumes that the 100% salinity tolerance thresholds have already been exceeded naturally for the predominant forage species, which is likely not the case). The baseline average soil EC to a depth of 48 inches in the Cottonwood Creek fields ranges from 1.5 to 6.2 dS/m, with an overall average of 4.2 dS/m for the seven contiguous field segments (Table 3). As discussed above in Section 3.1, long-term irrigation with undiluted produced water from Yates, Devon, and Barrett is unlikely to occur given the water management strategies to be employed. However, assuming that long-term irrigation with produced water were to occur with EC values ranging from 1.3 to 2.3 dS/m, it is unlikely that the average root zone EC would increase beyond the overall average of 4.2 dS/m for the seven contiguous field segments. Using the relationship described in Section 4.2 that relates irrigated water quality to the soil EC, the application of produced water with an EC of 2.3 dS/m would result in an estimated average soil EC of 3.5 dS/m (i.e., 2.3 dS/m x 1.5 = 3.5 dS/m). This is substantially less than the current average soil EC of 4.2 dS/m for the seven contiguous field segments. Therefore, it cannot be expected that there will be a measurable decrease in forage production on soils that receive produced water from Cottonwood Creek.

4.4.2 Specific Ion Toxicity

Sodium, chloride, and boron ions can be toxic to plants if their concentrations are too high in the irrigation water. Damage from sodium and chloride toxicity usually occurs only in woody plants such as tree and vine crops where soil salinity is extremely high or when saline water is used for sprinkler irrigation. Sodium and chloride toxicity normally results when these ions are taken up with the soil-water and accumulate in the leaves during water transpiration to an extent that result in damage to the plant. Given that woody crop species are not typically grown for agricultural production in the Cottonwood Creek drainage, it is assumed that potential sodium and chloride toxicity are not an issue.

Boron is essential for plant growth and development; however, it can be toxic to many crops at concentrations only slightly in excess of that needed for optimal growth. Boron tolerance in crops varies with climate, soil, crop variety, and rootstock. Tree and vine crops are the most sensitive, while field crops, such as alfalfa, are the most tolerant. Little data exists regarding the degree of boron tolerance in native range species of the semi-arid western U.S.; however, the general consensus is that these plants are moderately tolerant to tolerant. Boron concentrations in irrigation water between 2.0 and 4.0 mg/L are considered suitable for moderately tolerant crops, while boron concentrations greater than 4.0 mg/L are suitable for only tolerant species (Hanson et al., 1999). Water samples were not analyzed for boron concentrations; however boron concentrations are generally low in CBNG produced water.

4.5 Assessment of Potential Livestock Impacts

The soil and vegetation potential impact assessment demonstrates that the use of Cottonwood Creek water for irrigation, following CBNG development in the Cottonwood Creek drainage, will not lead to a measurable decrease in forage production. This in turn, indicates that there will be no measurable decrease in livestock production from a decrease in available forage.

To assess the available surface water quality for use as drinking water by livestock, the CBNG produced water quality data was compared to the current draft Section 20 Agricultural Use Protection Policy (WYDEQ, 2006), and suggested guidelines for levels of toxic substances in livestock drinking water (National Academy of Sciences, 1972 and 1974). The CBNG produced water meets all livestock drinking water guidelines (Table 4). In particular, chloride, fluoride, and sulfate, are all well below established livestock drinking water guidelines. Based on this assessment, the quality of the CBNG produced water will not cause a measurable decrease in livestock production.

5.0 EFFLUENT LIMIT DERIVATION & SECTION 20 COMPLIANCE

The current Section 20 Agricultural Use Protection Policy (WYDEQ, 2006) states that, for the purposes of establishing effluent limits for EC, the relationship between soil EC values and irrigation water EC values will be:

$$EC\ (soil) = 1.5 \times EC\ (water).$$

In other words, the soil EC will be divided by the soil concentration factor of 1.5 to establish the discharge EC limit. With an average soil EC to a depth of 48 inches of 4.2 dS/m, the discharge EC limit should be 2.8 dS/m (4.2 dS/m ÷ 1.5 = 2.8 dS/m). The Hanson et al. (1999) diagram is then used to extrapolate an effluent limit for SAR. The effluent limit for SAR is determined in conjunction with EC so that the relationship of SAR to EC remains within the "no reduction in rate of infiltration" zone (see Figure 1 of Hanson et al., 1999); or, more simply, SAR is determined using the following equation:

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

Therefore with an EC of 2.8 dS/m, the corresponding SAR effluent limit would be 17.

The Section 20 analysis presented herein demonstrates that discharge of CBNG produced water into Cottonwood Creek and its tributaries by Yates, Devon and Barrett, will not cause a measurable decrease in crop or livestock production. This conclusion is based on the following findings:

- *Potential Impacts to Soils.* The EC-SAR values for the four different produced water samples and the EC-SAR of the average produced water were compared to the EC-SAR guidelines presented in Ayers and Westcot (1985) and Hanson et al. (1999) - all produced water samples are within the "no reduction in infiltration" zone.

- *Potential Impacts to Vegetation.* The long-term application of produced water with an EC of 2.3 dS/m would result in an estimated average soil EC of 3.5 dS/m - which is substantially less than the currently measured average soil EC of 4.2 dS/m.
- *Potential Impacts to Livestock.* The CBNG produced water meets all livestock drinking water guidelines.

In summary, based on the analyses described herein for the water management conditions proposed by Yates, Devon and Barrett, and the proposed Tier 2-based effluent limits for EC and SAR, the proposed discharges will not result in a measurable decrease in agricultural production, and are therefore compliant with Chapter 1, Section 20 of the Wyoming Surface Water Rules and Regulations.

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Table 1. Cottonwood Creek irrigated fields and soil sub-sampling units.[1]

Site	Spreader Dikes	Size[2]	Number of Sub-sampling locations[3]	Location	Section(s)
		acres			
Field 1	-	32	9	T 43 N R 75 W	25, 26, 35
Field 2	CC1-CC3	8.3	5	T 43 N R 75 W	22, 23, 26
Field 3	CC4-CC7	22	7	T 43 N R 75 W	22
Field 4	CC8-CC25	62	9	T 43 N R 75 W	16, 21, 22
Field 5	CC26-CC40	86	9	T 43 N R 75 W	16, 17, 20, 21
Field 6	CC41-CC45	46	5	T 43 N R 75 W	17, 18, 19, 20
Field 7	CC46-CC55	39	5	T 43 N R 75 W	19

Notes

1 Samples were collected on December 5-6, 2006 by KC Harvey, Inc. using a Giddings Probe. Samples were analyzed by Energy Laboratories, Inc., Helena, Montana.

2 Field size was calculated from the delineated field boundary for Field 1 and based off the Cottonwood Creek spreader dike system water right permit for Fields 2 through 7 (Wyoming State Engineer's Office, Permit No. 32966, Approval date: April 9, 2004).

3 The number of sub-sampling locations within each field were selected based on site topography and NRCS soil mapping units.

Table 2. Soil physical analysis results for the Cottonwood Creek site.[1,2]

Site	Depth	Texture	Sand	Silt	Clay	Surface Clay Mineralogy[3]	Saturation Percentage	Organic Matter
	inches					%		
Field 1	0-6	Clay Loam	21	47	32	Smectite 46 Illite 31 Kaolinite 21 Chlorite 2	56	1.8
	6-12	Loam	40	37	23		41	
	12-24	Loam	35	43	22		43	
	24-36	Sandy Loam	56	26	18		37	
	36-48	Sandy Loam	74	14	12		30	
	48-72	Sandy Loam	70	17	13		30	
	72-96	Sandy Loam	58	24	18		35	
Field 2	0-6	Silty Clay Loam	16	53	31	Smectite 40 Illite 36 Kaolinite 21 Chlorite 3	58	3.1
	6-12	Loam	34	44	22		44	
	12-24	Loam	32	43	25		46	
	24-36	Loam	34	40	26		48	
	36-48	Loam	30	45	25		50	
	48-72	Clay Loam	31	38	31		54	
	72-96	Clay Loam	34	38	28		45	
Field 3	0-6	Silty Clay Loam	20	47	33	Smectite 49 Illite 28 Kaolinite 18 Chlorite 5	65	3.3
	6-12	Loam	35	41	24		47	
	12-24	Sandy Loam	70	18	12		33	
	24-36	Silty Loam	24	50	26		57	
	36-48	Loam	48	33	19		38	
	48-72	Loam	52	28	20		41	
	72-96	Sandy Loam	62	22	16		36	
Field 4	0-6	Silty Clay Loam	19	49	32	Smectite 42 Illite 32 Kaolinite 21 Chlorite 5	61	2.6
	6-12	Loam	31	45	24		46	
	12-24	Loam	44	36	20		42	
	24-36	Loam	34	43	23		46	
	36-48	Loam	45	35	20		40	
	48-72	Loam	50	31	19		38	
	72-96	Sandy Loam	68	21	11		29	
Field 5	0-6	Clay Loam	22	44	34	Smectite 46 Illite 27 Kaolinite 18 Chlorite 9	61	3.4
	6-12	Loam	32	42	26		49	
	12-24	Clay Loam	27	43	30		55	
	24-36	Loam	45	32	23		45	
	36-48	Silty Loam	62	22	16		35	
	48-72	Silty Loam	76	14	10		30	
	72-96	Loam	45	31	24		46	
Field 6	0-6	Silty Clay Loam	13	52	35	Smectite 50 Illite 25 Kaolinite 20 Chlorite 5	64	3.4
	6-12	Silty Clay Loam	14	54	32		61	
	12-24	Silty Clay Loam	9	54	37		64	
	24-36	Loam	32	43	25		51	
	36-48	Sandy Loam	54	31	15		39	
	48-72	Sandy Loam	65	21	14		37	
	72-96	Sandy Loam	63	23	14		34	
Field 7	0-6	Silty Clay	11	49	40	Smectite 50 Illite 25 Kaolinite 18 Chlorite 7	65	3.1
	6-12	Clay Loam	29	42	29		54	
	12-24	Loam	42	38	20		44	
	24-36	Sandy Loam	54	29	17		35	
	36-48	Sandy Loam	62	24	14		37	
	48-72	Sandy Loam	57	28	15		41	
	72-96	Sandy Clay Loam	69	8	23		32	

Notes:

1 Samples were collected on December 5-6, 2006 by KC Harvey, Inc. using a Giddings Probe. Samples were analyzed by Energy Laboratories, Inc., Helena, Montana.

2 Abbreviations used are as follow: % = percent; "-" = sample was not analyzed for the given parameter.

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. on 12/18/2006.

Table 3. Soil chemical analysis results for the Cottonwood Creek site.[1,2]

Site	Depth	pH	Electrical Conductivity at 25° 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 1	0-6	7.6	0.55	0.55	3.0	0.92	0.80	0.57	30	0.40	1.3		5.2
	6-12	7.6	0.55		2.9	1.1	0.93	0.66	19	0.40	2.1		5.0
	12-24	7.5	1.9		14	5.5	2.9	0.93	21	0.50	2.3		5.1
	24-36	7.4	2.2	1.5	16	6.4	4.5	1.3	17	0.60	3.3	2.9	4.1
	36-48	7.7	1.4		7.5	2.9	3.8	1.7	10	0.40	4.1		3.5
	48-72	7.6	2.3		17	6.9	4.8	1.4	12	0.60	4.7		3.7
	72-96	7.5	3.0		24	9.1	5.7	1.4	17	0.50	3.0		5.7
Field 2	0-6	7.5	0.73	0.67	5.1	1.4	0.90	0.48	33	0.40	1.3		5.6
	6-12	7.5	0.60		4.1	1.4	1.2	0.70	24	0.40	1.9		5.3
	12-24	7.6	3.7		22	10	18	4.5	24	1.6	6.8		5.5
	24-36	7.8	5.0	3.8	18	14	40	10	28	3.9	14	10.6	5
	36-48	7.9	5.8		19	18	53	12	25	5.1	20		5.2
	48-72	7.9	5.0		15	15	45	12	29	6.1	21		5.0
	72-96	7.8	4.4		19	16	33	7.9	24	3.0	13		4.8
Field 3	0-6	7.6	4.1	5.2	19	18	29	6.7	37	3.0	8.3		5.5
	6-12	7.7	6.2		20	25	55	12	22	3.9	17		4.7
	12-24	7.9	6.6		19	25	58	12	11	2.1	19		3.7
	24-36	7.9	5.7	5.1	17	21	51	12	29	5.9	20	14.4	5.6
	36-48	7.6	2.9		20	9.7	12	3.2	19	1.1	5.9		4.6
	48-72	7.7	3.5		20	13	19	4.6	19	1.6	8.3		4.5
	72-96	7.7	2.8		21	11	12	3.0	15	1.0	6.5		6.7
Field 4	0-6	7.6	0.58	0.51	4.1	1.3	1.2	0.71	37	0.40	1.1		5.4
	6-12	7.5	0.44		3.2	1.0	1.3	0.92	30	0.50	1.6		5.4
	12-24	7.6	2.7		18	7.2	16	4.4	23	1.3	5.8		4.6
	24-36	7.6	2.9	2.4	19	8.2	16	4.3	25	1.8	7.1	6.3	5
	36-48	7.7	3.8		18	15	27	6.5	20	2.3	11		4.5
	48-72	7.5	2.9		20	11	16	4.1	21	1.6	7.3		4.6
	72-96	7.7	2.9		20	9.4	12	3.2	14	1.1	8.3		5.7
Field 5	0-6	7.6	2.7	3.7	20	9.0	11	3.0	38	1.7	4.4		5.1
	6-12	7.7	4.7		18	13	37	9.3	25	3.5	14		5.2
	12-24	8.1	6.7		16	21	66	15	29	8.8	30		5.5
	24-36	8.1	6.4	5.4	16	24	62	14	19	6.9	37	22.3	4.9
	36-48	7.9	4.9		18	16	39	9.4	18	2.3	13		5.6
	48-72	7.8	4.0		21	14	26	6.1	14	1.4	10		3.9
	72-96	7.3	3.3		9.5	9.1	27	8.8	32	3.1	9.5		5.5
Field 6	0-6	7.5	1.5	3	7.3	2.5	7.6	3.4	41	1.5	3.6		5.1
	6-12	7.7	4.5		18	10	37	9.9	40	4.8	12		5.5
	12-24	8.1	7.4		18	20	70	16	40	9.4	23		5.6
	24-36	8.2	7.4	6.2	18	27	76	16	33	6.9	21	18.2	5.3
	36-48	8.1	7.3		18	23	67	15	20	4.1	21		4.6
	48-72	7.9	4.5		18	18	29	6.9	17	1.5	8.6		4
	72-96	7.7	3.8		21	13	22	5.2	18	1.3	7.0		4.4
Field 7	0-6	7.6	0.77	1.94	4.0	1.6	2.9	1.7	47	1.1	2.3		4.9
	6-12	7.6	3.1		17	8.9	18	5.2	37	3.2	8.7		4.8
	12-24	8.0	6.2		20	17	55	13	26	5.4	21		4.8
	24-36	8.0	6.2	4.9	20	19	53	12	19	2.9	15	13.6	6.2
	36-48	7.9	5.1		17	18	36	8.4	18	2.4	13		4.4
	48-72	7.9	4.9		21	18	31	6.9	15	1.8	12		4.9
	72-96	7.9	4.2		19	14	28	6.8	9.3	1.6	18		4.6
			Average EC:	4.2							**Average ESP:**	12.6	

Notes:

1 Samples were collected on December 5-6, 2006 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/L = milliequivalents per liter; meq/100 g = milliquivalents 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 4. Expected CBNG produced water quality in the Cottonwood Creek area.[1]

Analyte	Units	Livestock Watering Criteria[2]	Yates[3] Outfall WY0049352-001	Yates[3] Outfall WY0049352-002	Devon[4] Outfall WY0046612	Barrett[5] Outfall WY0046612	Average CBNG Produced Water Quality[6]
pH	*s.u.*	6.5 to 9	7.3	7.3	7.4	7.4	7.4
Electrical Conductivity (EC)	*dS/m*	7.5	1.8	1.7	1.3	2.3	1.8
Total Dissolved Solids (TDS)	*mg/L*	5000	-	-	800	1470	1135
Sodium Adsorption Ratio (SAR)		-	8.5	8.6	6.1	7.8	7.6
Anions							
Bicarbonate	*mg/L*	-	1300	1200	900	1730	1283
Chloride	*mg/L*	2000	7.0	6.0	7.0	4.0	6.0
Fluoride	*mg/L*	4.0	0.80	0.8	-	0.9	0.83
Sulfate	*mg/L*	3000	<1	1.0	nd	3.0	2.0
Cations							
Calcium	*mg/L*	-	76	67	59	134	84
Magnesium	*mg/L*	-	28	24	21	54	32
Potassium	*mg/L*	-	10	9.0	-	20	13
Sodium	*mg/L*	-	340	320	220	422	326
Metals[7]							
Arsenic	*µg/L*	20	-	-	0.80	2.2	1.5
Boron	*µg/L*	5000	-	-	-	-	-
Cadmium	*µg/L*	50	-	-	nd	<0.1	<0.1
Chromium	*µg/L*	1000	-	-	-	-	-
Copper	*µg/L*	500	-	-	nd	<1	<1
Lead	*µg/L*	100	-	-	nd	<2	<2
Mercury	*µg/L*	10	-	-	nd	<0.06	<0.06
Selenium	*µg/L*	50	-	-	nd	<5	<5
Zinc	*µg/L*	2500	-	-	nd	<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 parameter. Samples were analyzed by Energy Laboratories, Inc. Gillette, WY.

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

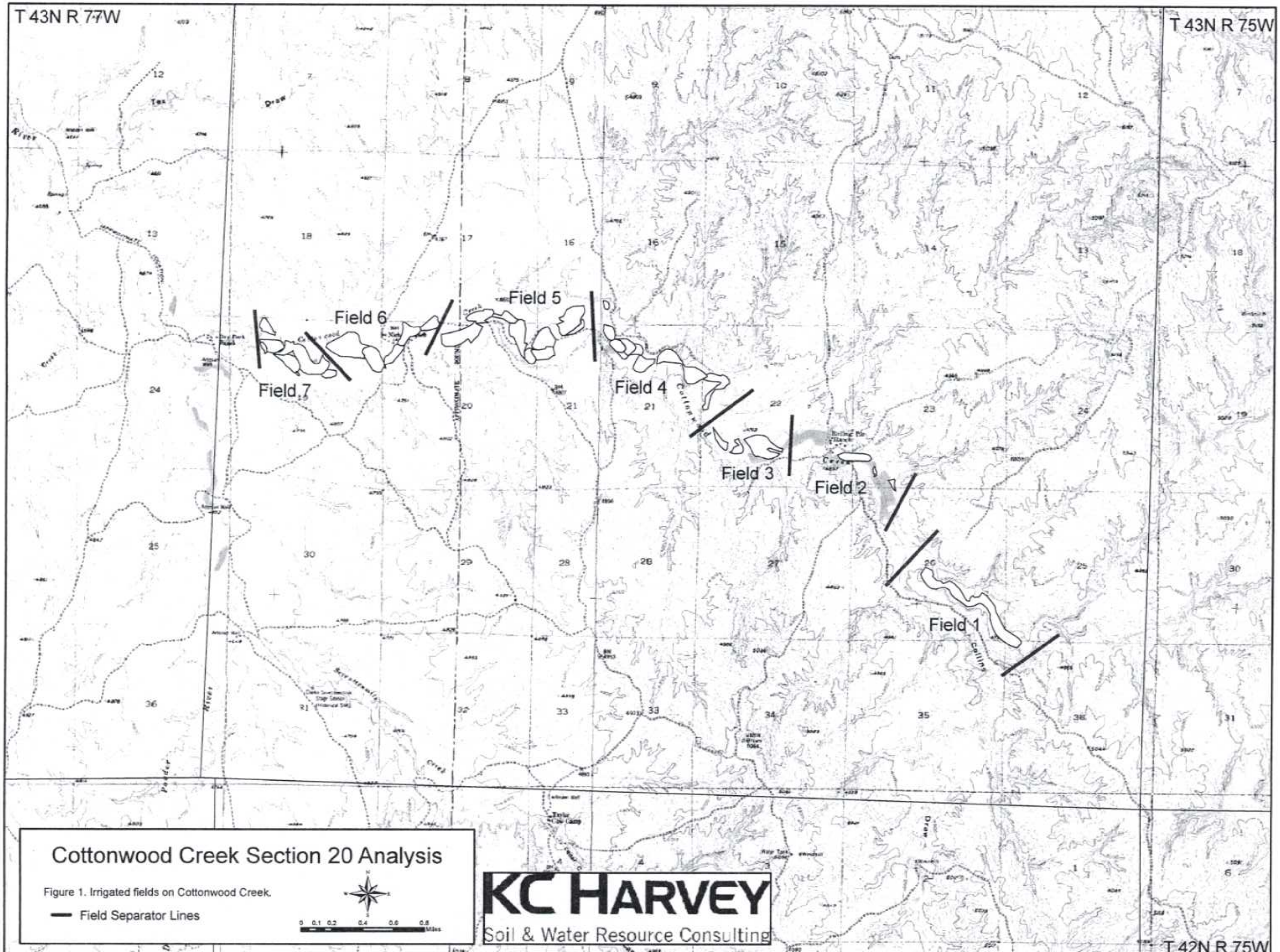
3 Outfall WY0049352-001 was sampled on 7/21/2006; Outfall WY49352-002 was sampled on two occasions, 7/21/2006 and 9/05/2006, average values are listed. All samples were collected by Yates.

4 Outfall WY0046612 is located in the NESE of Section 28 in Township 42 N, Range 75 W. The sample was collected on 9/21/2004 by Devon.

5 Outfall WY0046612 is located in the NESE of Section 28 in Township 42 N, Range 75 W. The sample was collected on 4/17/2006 by Devon.

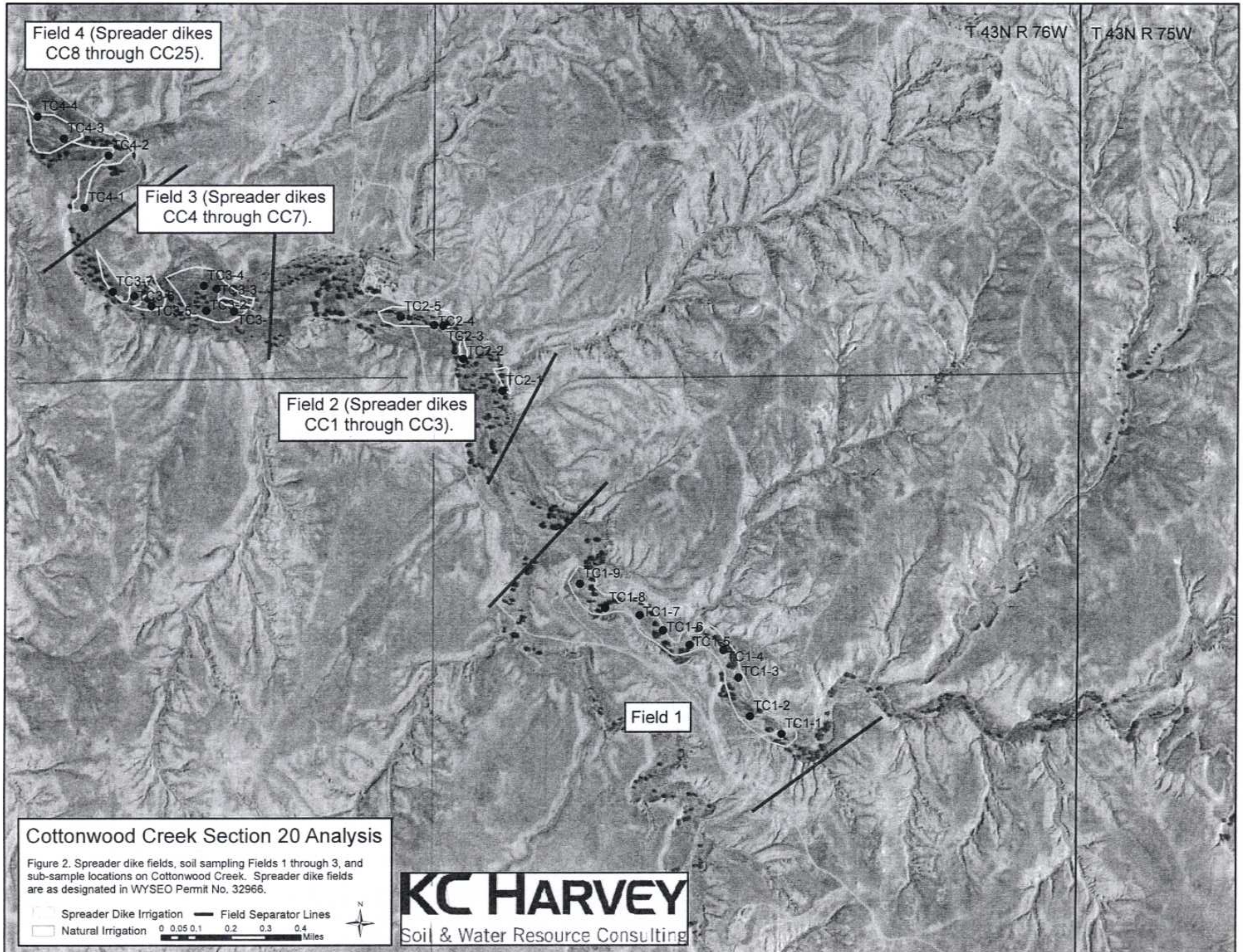
6 The median pH value is reported.

7 Arsenic and selenium are quantified as total recoverable metals; and, boron, cadmium, chromium, copper, lead, mercury, and zinc are quantified as dissolved metals.



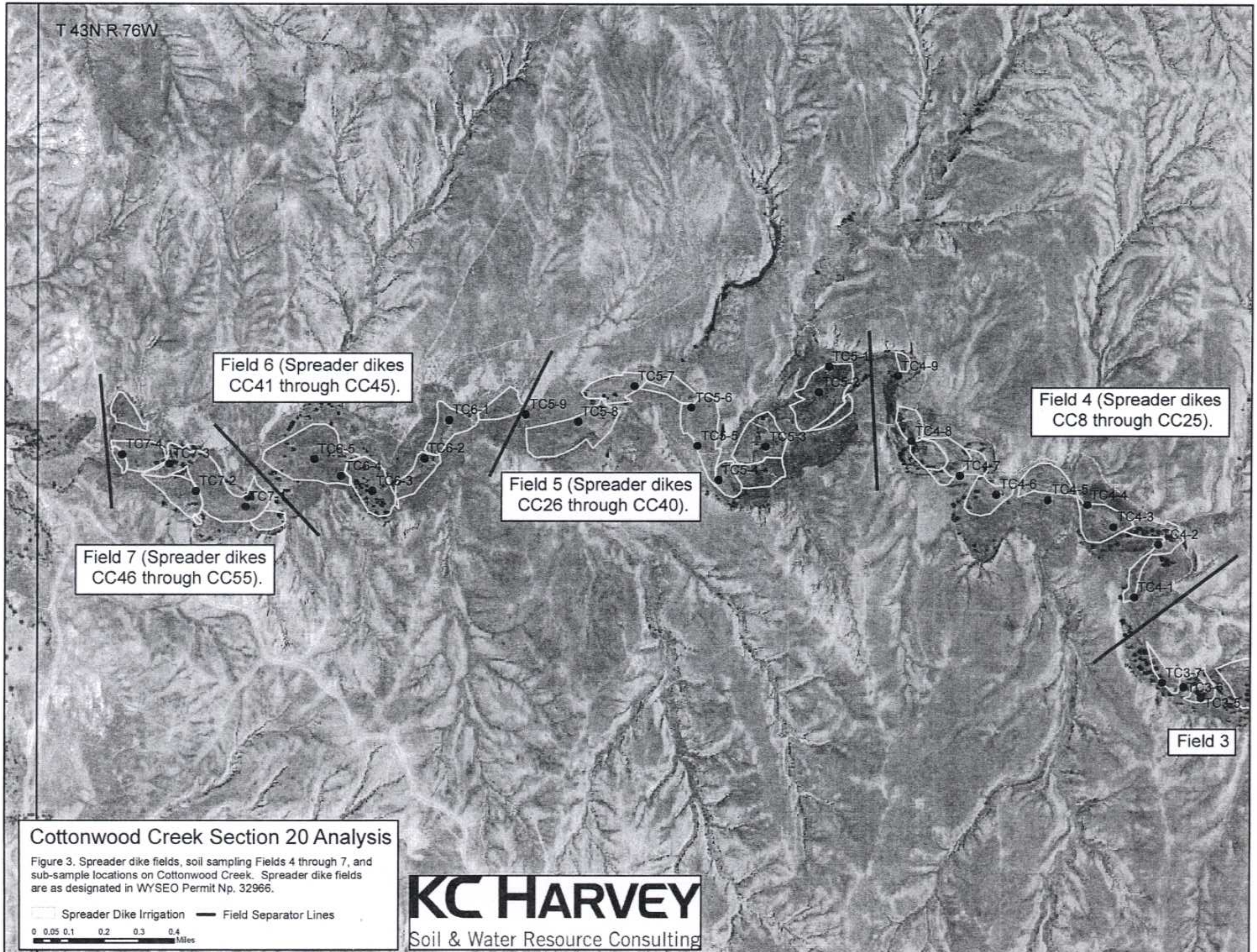
Cottonwood Creek Section 20 Analysis

Figure 1. Irrigated fields on Cottonwood Creek.



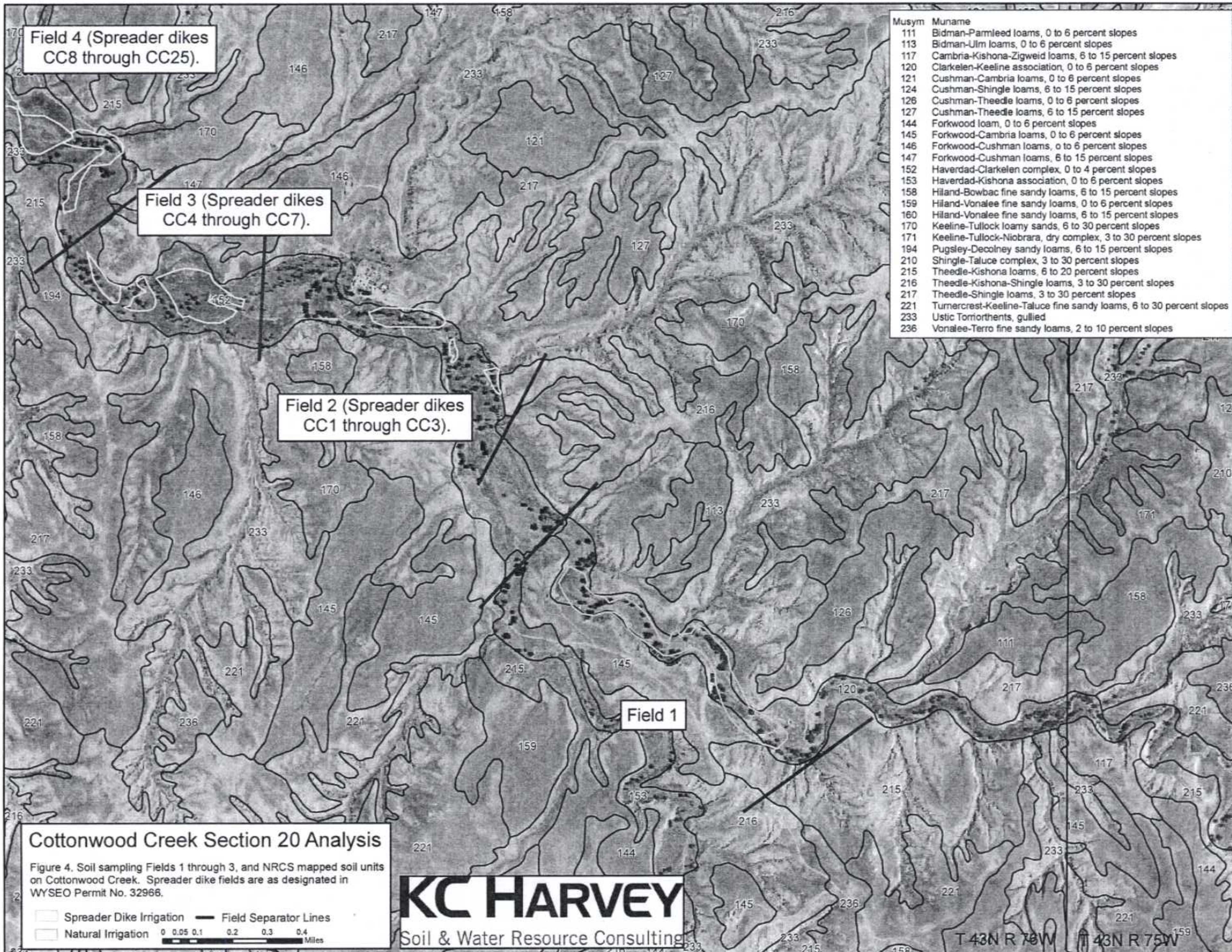
Cottonwood Creek Section 20 Analysis

Figure 2. Spreader dike fields, soil sampling Fields 1 through 3, and sub-sample locations on Cottonwood Creek. Spreader dike fields are as designated in WYSEO Permit No. 32966.



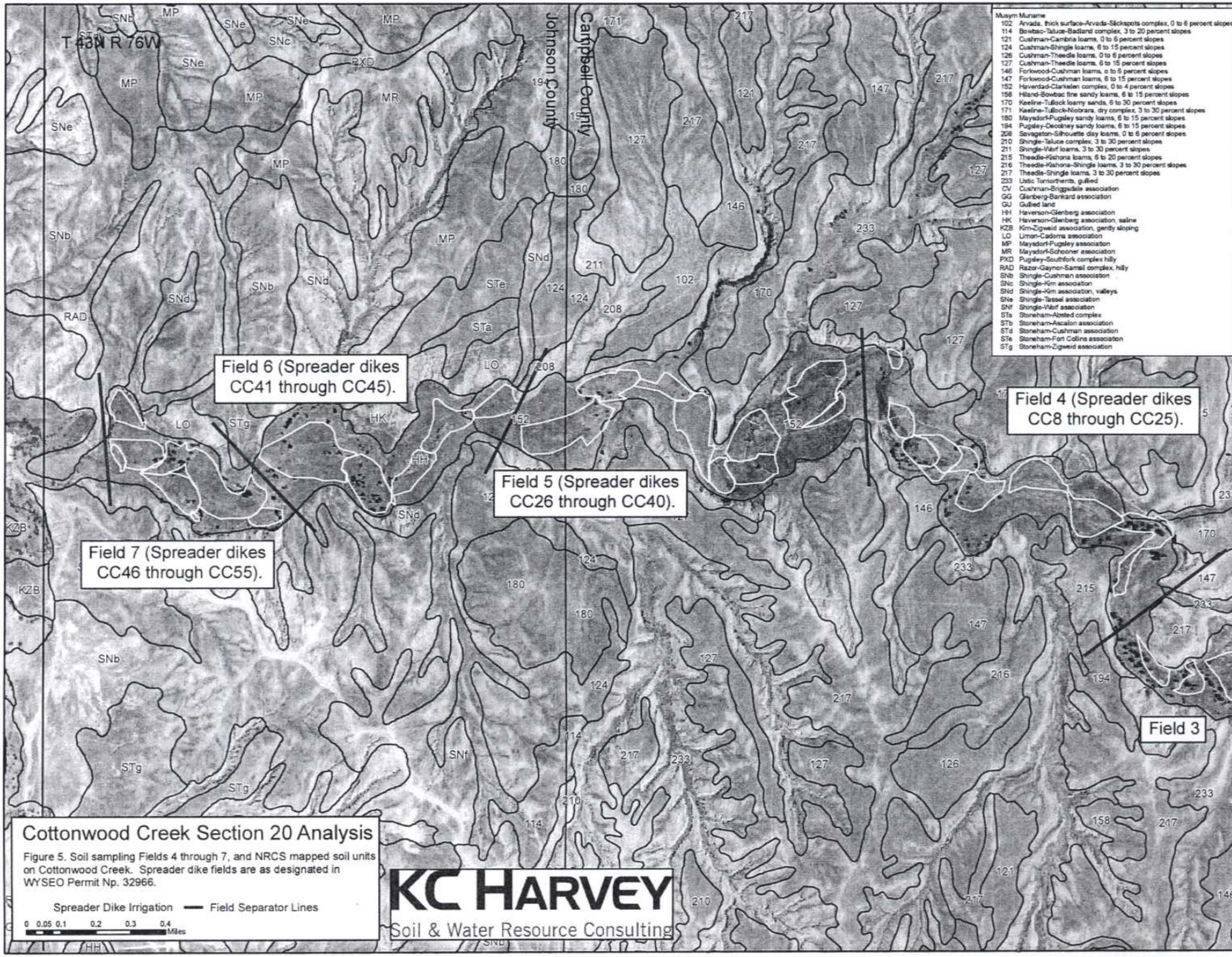
Cottonwood Creek Section 20 Analysis

Figure 3. Spreader dike fields, soil sampling Fields 4 through 7, and sub-sample locations on Cottonwood Creek. Spreader dike fields are as designated in WYSEO Permit Np. 32966.



Cottonwood Creek Section 20 Analysis

Figure 4. Soil sampling Fields 1 through 3, and NRCS mapped soil units on Cottonwood Creek. Spreader dike fields are as designated in WYSEO Permit No. 32966.



Cottonwood Creek Section 20 Analysis

Figure 5. Soil sampling Fields 4 through 7, and NRCS mapped soil units on Cottonwood Creek. Spreader dike fields are as designated in WYSEO Permit Np. 32966.

Appendix A

LOCATION CLARKELEN WY

Established Series
CAP-GFK
11/2005

CLARKELEN SERIES

The Clarkelen series consists of very deep, well, moderately well or somewhat excessively drained soils formed in stratified recent stream alluvium from mixed sedimentary sources. Clarkelen soils are on flood plains and terraces. Slopes range from 0 to 6 percent. The average annual precipitation is about 12 inches, and the mean annual air temperature is about 46 degrees F.

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

TYPICAL PEDON: Clarkelen fine sandy loam - utilized as rangeland. (Colors are for dry soil unless otherwise stated)

A--0 to 6 inch; grayish brown (10YR 5/2) fine sandy loam, dark grayish brown (10YR 4/2) moist; weak fine granular structure; soft, very friable; nonsticky and nonplastic; common fine and very fine, and few medium roots throughout; calcium carbonate disseminated throughout; slightly effervescent; slightly alkaline; gradual smooth boundary. (1 to 6 inches thick)

C1--6 to 20 inches; light brownish gray (10YR 6/2) weakly stratified fine sandy loam and loamy fine sand, dark grayish brown (10YR 4/2) moist; massive; thin stratifications; soft, very friable, nonsticky and nonplastic; common fine and very fine, and few medium roots throughout; calcium carbonate disseminated throughout; slightly effervescent; moderately alkaline; abrupt wavy boundary.

C2--20 to 30 inches; light brownish gray (10YR 6/2) and pale brown (10YR 6/3) stratified loam and very fine sandy loam, grayish brown (10YR 5/2) moist; massive; thin stratifications; slight hard, friable, nonsticky and nonplastic; few fine and very fine roots; calcium carbonate disseminated throughout; slightly effervescent; moderately alkaline; abrupt wavy boundary.

C3--30 to 51 inches; light brownish gray (10YR 6/2) fine sand, grayish brown (10YR 5/2) moist; single grain; loose, nonsticky and nonplastic; few fine roots; calcium carbonate disseminated throughout; slightly effervescent; moderately alkaline; abrupt smooth boundary.

C4--51 to 60 inches; grayish brown (10YR 5/2) fine sandy loam, dark grayish brown (10YR 4/2) moist; massive; thin stratifications; slightly hard, friable, nonsticky and nonplastic; few fine roots; calcium carbonate disseminated throughout; slightly effervescent; strongly alkaline.

TYPE LOCATION: Niobrara County, Wyoming; about 250 feet north and 100 feet east of the southwest corner of Sec. 14, T. 38 N., R. 64 W.

RANGE IN CHARACTERISTICS: This soil typically lacks horizons of continuous carbonate accumulation. Depth to carbonates ranges from 0 to 8 inches. Rock fragments are typically less than 5 percent but may range to 15 percent. Organic matter content decreases irregularly with depth; and thin, highly variable textural strata usually occur between 6 and 24 inches. The particle-size control section contains from 5 to 18 percent clay and is sandy loam, fine sandy loam or loam when averaged. The soil is dry in the moisture control section more than half the time cumulative that the soil temperature at a depth of 20 inches is 41 degrees F. and is never moist in all parts for as long as 60 consecutive days when the soil temperature at a depth of 20 inches is 41 degrees F., which occurs about April 21-27, but is dry in all parts of the moisture control section for at least 60 consecutive days from July 15 to October 25 and for at least 90 cumulative days during this period. The mean annual soil temperature is 47 to 52 degrees F., and the soil temperature at a depth of 20 inches is 41 degrees F. or more for 175 to 192 days.

The A horizon has hue of 10YR or 2.5Y, value of 4 to 7 dry and 3 to 6 moist, and chroma of 2 to 4. Texture typically is sandy loam or fine sandy loam but may range from loamy sand to clay loam depending upon the most recent deposition. Reaction ranges from neutral to moderately alkaline. It has an EC of 0 to 4 mmhos/cm. Nitrogen and phosphorus levels are not abnormally enriched. Some pedons have an AC horizon up to 8 inches thick.

The C horizon has hue of 7.5YR, 10YR or 2.5Y, value of 5 to 7 dry and 4 to 6 moist, and chroma of 2 to 4. Texture centers on sandy loam, fine sandy loam or loam, but strata of very fine sandy loam, loam, silt loam, loamy fine sand, loamy sand, fine sand or sand of varying thickness occur. Skeletal material may occur below 40 inches in some pedons. Reaction ranges from slightly alkaline to strongly alkaline. EC is typically 4 mmhos/cm or less but may range up to 8 when irrigated or where it receives saline discharge from surrounding shale beds.

COMPETING SERIES: These are the Cameo, Colorow, Glenberg, Kornman, Radnik, Redbank and Tapicito series (Colorow, Kornman, Radnik and Redbank will likely compete when their classifications are updated). Cameo, Radnik and Tapicito soils are usually dry in the moisture control section during April, May, and early June. Colorow soils are mottled in the lower part of the particle-size control section. Glenberg soils have more favorable temperature and moisture relationships for growing crops (soil temperature of more than 52 degrees and frost-free period of more than 130 days). Kornman soils have over-thickened nitrogen- and phosphate- enriched, manmade surface horizons resulting from application of silty irrigation water over long periods of time. Redbank soils have hue of 7.5YR or redder.

GEOGRAPHIC SETTING: Clarkelen soils are on flood plains and terraces adjacent to floodplains. Slopes are 0 to 6 percent. The soils formed in stratified but dominantly moderately coarse textured recent stream alluvium originally weathered from sedimentary rock. Elevation is 3,500 to 6,200 feet. The average annual precipitation is 12 inches with over half falling in April, May, and June and less than one inch falling in each month of July, August, September, and October. Precipitation ranges from 10 to 14 inches. The mean annual air temperature ranges from 44 to 49 degrees F. The frost-free season is about 105 to 130 days.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Bigwin, Draknab, Dwyer, Haverdad and Orpha soils. Bigwin soils have an aquic moisture regime. Draknab soils have sandy control sections. Dwyer and Orpha soils have a more uniform texture and a uniform decrease in organic carbon with depth. Haverdad soils have fine-loamy control sections.

DRAINAGE AND PERMEABILITY: Well, moderately well or somewhat excessively drained; slow runoff; moderately rapid permeability. The soil is subject to occasionally flooding for brief or very brief periods following intense storms in spring and summer or from snowmelt in spring.

USE AND VEGETATION: These soils are dominantly used for grazing. Potential vegetation is needleandthread, western wheatgrass, and silver sagebrush with scattered stands of cottonwoods.

DISTRIBUTION AND EXTENT: The Powder River Basin and adjacent areas of eastern Wyoming. Series is of moderate extent.

MLRA OFFICE RESPONSIBLE: Bismarck, North Dakota

SERIES ESTABLISHED: Converse County, Wyoming; 1982.

REMARKS: Diagnostic horizons and features recognized in this pedon are:

Ochric epipedon - 0 to 6 inches (A horizon)

MLRR- G

SIRs- WY0503, WY0804, WY0857, WY0993 WY1003, WY1004, WY1005, WY1157, WY1170, WY1176, WY1254, WY1255, WY1402.

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.

LOCATION HAVERDAD WY+MT UT

Established Series
Rev. JEI/MCS/SSP
06/2002

HAVERDAD SERIES

The Haverdad series consists of very deep, well drained soils formed in stratified alluvium on flood plains and low terraces. Permeability is moderate. Slopes range from 0 to 6 percent. The mean annual precipitation is about 11 inches, and the mean annual temperature is about 45 degrees F.

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

TYPICAL PEDON: Haverdad loam - utilized as rangeland. (Colors are for dry soil unless otherwise stated)

A--0 to 4 inches; pale brown (10YR 6/3) loam, dark grayish brown (10YR 4/2) moist; moderate medium subangular structure parting to weak fine granular; slightly hard, friable, slightly sticky and slightly plastic; many fine roots throughout; carbonates are disseminated throughout; slightly effervescent; moderately alkaline (pH 8.0); gradual smooth boundary. (2 to 8 inches thick)

C1--4 to 14 inches; pale brown (10YR 6/3) loam, brown (10YR 4/3) moist; moderate medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; common fine roots throughout; carbonates are disseminated throughout; slightly effervescent; moderately alkaline (pH 8.2); clear smooth boundary.

C2--14 to 30 inches; pale brown (10YR 6/3) loam, stratified with fine sandy loam, sand loam, clay loam, and silt loam, brown (10YR 4/3) moist; weak fine and medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; few fine and very fine roots throughout; carbonates are disseminated throughout; slightly effervescent; strongly alkaline (pH 8.6); gradual smooth boundary.

C3--30 to 60 inches; pale brown (10YR 6/3) clay loam, stratified with fine sandy loam, loam, silt loam, and silty clay loam, brown (10YR 5/3) moist; weak fine and medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; few fine and very fine roots throughout; carbonates are disseminated throughout; slightly effervescent; strongly alkaline (pH 8.6); gradual smooth boundary.

TYPE LOCATION: Niobrara County, Wyoming; about 2,600 feet north and 750 feet east of the southwest corner of Sec. 12, T 38 N, R 65 W. lat. 43 degrees 17 minutes 2 seconds north and long. 104 degrees 36 minutes 54 seconds west.

RANGE IN CHARACTERISTICS:
Soil moisture: The soil is dry in the moisture control section more than half the time cumulative that the soil temperature at a depth of 20 inches is 41 degrees F. or more. This soil is moist for 60 consecutive days when the soil temperature at 20 inches is 41 degrees F., which occurs about April 21-27, but is dry in all parts of the moisture control section for at least 60 consecutive days from July 15 to October 25 and for at least 90 cumulative days during this period.

Mean annual soil temperature: 48 to 53 degrees F. and the soil temperature at a depth of 20 inches is 41 degrees F. or more for 175 to 195 days.

Organic carbon content: .5 to 1.0 percent and decreases irregularly with depth
Rock fragments: 0 to 15 percent gravel
EC (mmhos/cm): 0 to 8 mmhos throughout but where irrigated some soils may range up to 16 mmhos
Calcium sulfate occurs in some pedons.
The soil is typically calcareous to the surface, but some pedons are leached as deep as 20 inches.

A horizon:
Hue: 10YR or 2.5Y
Value: 4 through 6 dry, 3 through 5 moist
Chroma: 2 through 4 dry or moist
Texture: loam, clay loam, silt loam, silty clay loam, very fine sandy loam, fine sandy loam, sandy loam
Reaction: slightly alkaline through strongly alkaline

Some pedons have an AC horizon.

C horizon:
Hue: 10YR or 2.5Y
Value: 5 through 7 dry, 4 to 6 moist
Chroma: 2 through 4 dry or moist
Texture: variable but when averaged is loam or light clay loam with 18 to 35 percent clay
Calcium carbonate equivalent: 1 to 15 percent which changes erratically between strata
Reaction: slightly alkaline through strongly alkaline

COMPETING SERIES: These are the Hamburn, Manikan, San Mateo, and Suwanee series.

Hamburn: have pedogenic accumulations of salt and SARs greater than 13
Manikan, and Suwanee: have hue of 7.5YR or redder
San Mateo: have soil moisture control sections that are drier during April, May, and June

GEOGRAPHIC SETTING:
Parent material: alluvium from mixed sources
Landform: floodplains and low terraces
Elevations: 3,500 to 6,500 feet
Slopes: 0 to 6 percent
Mean annual precipitation: about 11 inches, ranging 10 to 17, with over half of annual precipitation falling in April, May, and June
Mean annual temperature: about 45 degrees F. and ranges from 43 to 52 degrees F.
Frost-free period: 105 to 130 days

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Arvada, Forkwood, Kishona, and Shingle soils. Arvada soils have a natric horizon. Forkwood soils have an argillic horizon. Kishona soils lack stratification. Shingle soils have bedrock at a depth of 4 to 20 inches.

DRAINAGE AND PERMEABILITY: Well drained; slow runoff; moderate permeability. Flooding for brief periods occurs during spring runoff and after thunder showers.

USE AND VEGETATION: These soils are used principally for grazing. Principal native vegetation is big sagebrush, western wheatgrass, greasewood, and annual grasses and forbs.

DISTRIBUTION AND EXTENT: Big Horn Basin, central, eastern Wyoming, Colorado, and Utah.

MLRA OFFICE RESPONSIBLE: Lakewood, Colorado

SERIES ESTABLISHED: Washakie County, Wyoming; 1980.

REMARKS: Diagnostic horizons and features recognized in this pedon are:

Ochric epipedon - 0 to 6 inches (A)

The type location for this series was moved from Washakie County, Wyoming to its current location in Niobrara County, Wyoming to better reflect the moisture regime concept, June 2002.

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 KEELINE WY

Established Series
Rev. RLR/JAL
04/2002

KEELINE SERIES

The Keeline series consists of very deep, well or somewhat excessively drained soils formed in alluvium or eolian deposits derived from sandstone. Keeline soils are on upland ridgetops, hillslopes, terraces, benches, alluvial fans, and fan remnants. Slopes range from 0 to 40 percent. The mean annual precipitation is about 12 inches, and the mean annual temperature is about 46 degrees F.

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

TYPICAL PEDON: Keeline sandy loam on east facing shoulder slope of 4 percent utilized as rangeland. (Colors are for dry soil unless otherwise stated.)

A--0 to 3 inches; yellowish brown (10YR 5/4) sandy loam, brown (10YR 4/3) moist; weak fine subangular blocky and granular structure; soft, very friable, nonsticky and nonplastic; slightly effervescent; calcium carbonate disseminated; slightly alkaline (pH 7.6); abrupt smooth boundary. (2 to 8 inches thick)

Bw--3 to 8 inches; pale brown (10YR 6/3) sandy loam, brown (10YR 5/3) moist; weak medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; strongly effervescent; calcium carbonate disseminated; slightly alkaline (pH 7.8); clear smooth boundary. (0 to 7 inches thick)

Cl--8 to 17 inches; very pale brown (10YR 7/3) sandy loam, light yellowish brown (10YR 6/4) moist; massive; soft, very friable, nonsticky and nonplastic; strongly effervescent; calcium carbonatedisseminated; moderately alkaline (pH 8.2); gradual smooth boundary. (8 to 50 inches thick)

C2--17 to 30 inches; very pale brown (10YR 7/3) sandy loam, pale brown (10YR 6/3) moist; massive; soft, very friable, nonsticky and nonplastic; strongly effervescent; calcium carbonate disseminated; moderately alkaline (pH 8.2); gradual smooth boundary. (0 to 25 inches thick)

C3--30 to 60 inches; very pale brown (10YR 7/3) sandy loam, light yellowish brown (10YR 6/4) moist; massive; soft, very friable, nonsticky and nonplastic; strongly effervescent, calcium carbonate disseminated; moderately alkaline (pH 8.2).

TYPE LOCATION: Converse County, Wyoming; 2,100 feet north and 400 feet west of the SE corner of sec. 29, T. 40 N., R. 75 W. 43 degrees 24 minutes 27 seconds north latitude and 105 degrees 52 minutes 46 seconds west longitude.

RANGE IN CHARACTERISTICS: Free carbonates typically occur throughout the profile, but some pedons may be leached as much as 6 inches. The control section averages fine sandy loam or sandy loam with 5 to 18 percent clay. Rock fragments range from 0 to 15 percent. Some thin strata of coarser material may occur. The soil is dry in the moisture control section more than half the time cumulative that the soil temperature at a depth of 20 inches is 41 degrees F., which occurs about April 21-27, and is dry in all parts of the moisture control section for at least 60 consecutive days from July 15 to October 25 and for at least 90 cumulative days during this period. The mean annual soil temperature is 47 to 52 degrees F., and the soil temperature at a depth of 20 inches is 41 degrees F. or more for 175 to 192 days. EC ranges from 0 to 4 mmhos throughout the profile.

Bedrock is deeper than 60 inches.

The A horizon has hue of 7.5YR through 2.5Y, value of 5 through 7 dry, 4 or 5 moist, and chroma of 2 through 4. It is sandy loam and less commonly loamy sand, fine sandy loam, or loamy fine sand. Reaction is neutral to moderately alkaline.

The Bw horizon, when present, has the same properties of the A except for structure which is usually weak subangular blocky.

Some pedons have an AC horizon.

The C horizon has hue of 7.5YR through 5Y, value of 4 through 7 dry, 4 through 6 moist, and chroma of 2 through 4. Texture averages sandy loam or fine sandy loam. Some pedons have subhorizons of very fine sandy loam or loamy fine sand. Reaction is moderately or strongly alkaline and some pedons have weak, discontinuous accumulations of calcium carbonate.

COMPETING SERIES: These are the Cliff, Councelor, Henrieville, Nelman, Nelson, Oterodry, Pedrick, Shedado, Turnercrest, Uendal, Yarts, and Zia series. Nelman, Shedado, and Uendal soils have lithic contacts at depths of 20 to 40 inches. Nelson and Turnercrest soils have paralithic contacts at depths of 20 to 40 inches. Cliff, Councelor, Henrieville, Otero, Pedrick and Zia soils are not dry for 60 consecutive days in the moisture control section from July 15 to October 25. Yarts soils have 2.5YR through 7.5YR hues throughout.

GEOGRAPHIC SETTING: Keeline soils are on terraces, benches, alluvial fans, fan remnants, ridgetop and hillslope positions. Slopes are 0 to 40 percent. These soils formed in moderately coarse alluvium or eolian deposits derived from calcareous sandstone. Elevations are 3,500 to 6,200 feet. The average annual precipitation is 12 inches with over one-half of the annual precipitation falling in April, May, and June and less than one inch falling in each month of July, August, September, and October. Precipitation ranges from 10 to 14 inches. The mean annual temperature is about 46 degrees F.but ranges from 44 to 49 degrees F. The frost-free season is about 105 to 130 days.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Dwyer, Orpha , Tassel, Terro , Tullock, Turnercrest, and Vonalee soils. Dwyer, Orpha, and Tullock soils have sandy control sections. Tassel soils have paralithic bedrock at 10 to 20 inches. Terro and Vonalee soils have argillic horizons. Turnercrest soils have paralithic bedrock at 20 to 40 inches.

DRAINAGE AND PERMEABILITY: Well or Somewhat excessively drained; slow runoff; moderately rapid permeability.

USE AND VEGETATION: These soils are dominantly used for grazing. Potential native vegetation is needleandthread, prairie sandreed, Indian ricegrass, and little bluestem.

DISTRIBUTION AND EXTENT: Powder River Basin and adjacent areas of eastern Wyoming. Series is of moderate extent.

MLRA OFFICE RESPONSIBLE: Bozeman, Montana

SERIES ESTABLISHED: Converse County, Wyoming, North Part; 1983.

REMARKS: Diagnostic horizons and features recognized in this pedon are:

1. Ochric epipedon - 0 to 3 inches (A)

2. Ustic subgroup - Aridic moisture regime bordering on Ustic.

SIR- WY1293

LRR- G

National Cooperative Soil Survey
U.S.A.

Appendix B

DCM Science Laboratory, Inc.
12421 W. 49th Avenue, Unit #6
Wheat Ridge, CO 80033 - (303) 463-8270

Quantitative Clay Analysis (XRD)

Client:
Energy Laboratories, Inc.
3161 E. Lyndale
Helena, MT 59601

Analysis Date:	12-18-06
Reporting Date:	12-20-06
Receipt Date:	12-15-06
Client Job No.:	H11562
Project Title:	H06120086
DCMSL Project:	ELAB14

Client Sample No.:	**H06120086 001**
Clay Fraction <2µm	
Smectite	46
Illite	31
Kaolinite	21
Chlorite	2

An oriented clay mount (<2µm) was prepared for x-ray diffraction and scanned over a range of 3° to 45° 2Θ using CuKα radiation, 40kV, 25mA. The mounts were analyzed air dried (RH ~25%) and glycolated. Clay concentrations are based on peak areas and intensity factors measured in-house on known standards or computer calculated.

Ron Schott
Ron Schott, Analyst

ENERGY LABORATORIES, INC. • P.O. Box 5688 • 3161 East Lyndale Ave. • Helena, MT 59604
877-472-0711 • 406-442-0711 • 406-442-0712 fax • helena@energylab.com

Date: *04-Jan-07*

CLIENT: Yates Petroleum Corp
Project: Cottonwood Creek Section 20 Analysis
Sample Delivery Group: H06120086

CASE NARRATIVE

Sample 001 submitted to DCM Laboratory in Wheat Ridge, CO for Clay Mineralogy analysis. Attached is the original report.

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

Client: Yates Petroleum Corp
Project: Cottonwood Creek Section 20 Analysis
Workorder: H06120086

Report Date: 01/04/07
Date Received: 12/10/06

		Analysis		pH-SatPst	COND	Percent Sat	SAR	Ca-SatPst	Mg-SatPst	Na-SatPst	Sand	Silt	Clay	Texture
		Units		s_u_	mmhos/cm	%	unitless	meq/l	meq/l	meq/l	%	%	%	unitless
Sample ID	**Client Sample ID**	**Up**	**Low**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**
H06120086-001	Field 1 0-6	0	6	7.6	0.55	56.1	0.57	2.97	0.92	0.8	21	47	32	CL
H06120086-002	Field 1 6-12	6	12	7.6	0.55	41.4	0.66	2.93	1.07	0.93	40	37	23	L
H06120086-003	Field 1 12-24	12	24	7.5	1.91	43.0	0.93	14.3	5.47	2.93	35	43	22	L
H06120086-004	Field 1 24-36	24	36	7.4	2.23	37.2	1.3	16.3	6.39	4.52	56	26	18	SL
H06120086-005	Field 1 36-48	36	48	7.7	1.40	30.2	1.7	7.45	2.87	3.82	74	14	12	SL
H06120086-006	Field 1 48-72	48	72	7.6	2.30	30.4	1.4	17.4	6.93	4.75	70	17	13	SL
H06120086-007	Field 1 72-96	72	96	7.5	2.96	35.2	1.4	24.1	9.06	5.7	58	24	18	SL

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LABORATORY ANALYTICAL REPORT

Client: Yates Petroleum Corp
Project: Cottonwood Creek Section 20 Analysis
Workorder: H06120086

Report Date: 01/04/07
Date Received: 12/10/06

		Analysis		OM-WB	CEC	Lime	Na-Ext	Exch Na	ESP
		Units		%	meq/100g	%	meq/100g	meq/100g	%
Sample ID	**Client Sample ID**	**Up**	**Low**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**
H06120086-001	Field 1 0-6	0	6	1.81	30.1	5.2	0.42	0.4	1.3
H06120086-002	Field 1 6-12	6	12		19.3	5.0	0.45	0.4	2.1
H06120086-003	Field 1 12-24	12	24		20.9	5.1	0.62	0.5	2.3
H06120086-004	Field 1 24-36	24	36		16.6	4.1	0.72	0.6	3.3
H06120086-005	Field 1 36-48	36	48		10.3	3.5	0.54	0.4	4.1
H06120086-006	Field 1 48-72	48	72		11.6	3.7	0.69	0.6	4.7
H06120086-007	Field 1 72-96	72	96		17.4	5.7	0.72	0.5	3.0

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877-472-0711 • 406-442-0711 • 406-442-0712 fax • helena@energylab.com

Date: *03-Jan-07*

CLIENT: Yates Petroleum Corp
Project: CottonWood Creek Section 20 Analysis
Sample Delivery Group: H06120087

CASE NARRATIVE

The following samples were submitted to DCM Laboratories in Wheat Ridge, CO to be analyzed for Clay Minerlogy: Field 2 0-6"-001, Field 3 0-6"-008, Field 4 0-6"-015, Field 5 0-6"-022, Field 6 0-6"-029, Field 7 0-6"-036.

DCM Science Laboratory, Inc.
12421 W. 49th Avenue, Unit #6
Wheat Ridge, CO 80033 - (303) 463-8270

Quantitative Clay Analysis (XRD)

Client:
Energy Laboratories, Inc.
3161 E. Lyndale
Helena, MT 59601

Analysis Date: 12-18-06
Reporting Date: 12-20-06
Receipt Date: 12-15-06
Client Job No.: H11562
Project Title: H06120087
DCMSL Project: ELAB16

Client Sample No.:	**H06120087 001**	**H06120087 008**	**H06120087 015**	**H06120087 022**	**H06120087 029**	**H06120087 036**
Clay Fraction <2µm						
Smectite	40	49	42	46	50	50
Illite	36	28	32	27	25	25
Kaolinite	21	18	21	18	20	18
Chlorite	3	5	5	9	5	7

Oriented clay mounts (<2µm) were prepared for x-ray diffraction and scanned over a range of 3° to 45° 2Θ using CuKα radiation, 40kV, 25mA. The mounts were analyzed air dried (RH ~25%) and glycolated. Clay concentrations are based on peak areas and intensity factors measured in-house on known standards or computer calculated.

Ron Schott

Ron Schott, Analyst

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LABORATORY ANALYTICAL REPORT

Client: Yates Petroleum Corp
Project: CottonWood Creek Section 20 Analysis
Workorder: H06120087

Report Date: 01/03/07
Date Received: 12/10/06

		Analysis		pH-SatPst	COND	Percent Sat	SAR	Ca-SatPst	Mg-SatPst	Na-SatPst	Sand	Silt	Clay	Texture
		Units		s_u_	mmhos/cm	%	unitless	meq/l	meq/l	meq/l	%	%	%	unitless
Sample ID	**Client Sample ID**	**Up**	**Low**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**
H06120087-001	Field 2 0-6	0	6	7.5	0.73	57.6	0.48	5.05	1.42	0.9	16	53	31	SiCL
H06120087-002	Field 2 6-12	6	12	7.5	0.60	44.3	0.70	4.13	1.42	1.16	34	44	22	L
H06120087-003	Field 2 12-24	12	24	7.6	3.65	46.1	4.5	22.4	10.3	18.2	32	43	25	L
H06120087-004	Field 2 24-36	24	36	7.8	4.97	47.5	10	18.2	14.2	40.4	34	40	26	L
H06120087-005	Field 2 36-48	36	48	7.9	5.84	50.1	12	18.8	17.8	53.4	30	45	25	L
H06120087-006	Field 2 48-72	48	72	7.9	4.98	54.1	12	15.2	14.8	44.5	31	38	31	CL
H06120087-007	Field 2 72-96	72	96	7.8	4.44	44.8	7.9	18.5	16.3	33.1	34	38	28	CL
H06120087-008	Field 3 0-6	0	6	7.6	4.14	65.1	6.7	19.1	17.7	28.9	20	47	33	SiCL
H06120087-009	Field 3 6-12	6	12	7.7	6.22	46.6	12	19.9	24.6	55.4	35	41	24	- L
H06120087-010	Field 3 12-24	12	24	7.9	6.55	33.3	12	19.2	24.6	57.9	70	18	12	SL
H06120087-011	Field 3 24-36	24	36	7.9	5.69	56.7	12	16.9	20.9	50.5	24	50	26	SiL
H06120087-012	Field 3 36-48	36	48	7.6	2.91	37.5	3.2	20.2	9.71	12.2	48	33	19	L
H06120087-013	Field 3 48-72	48	72	7.7	3.48	40.8	4.6	19.9	13.2	18.7	52	28	20	L
H06120087-014	Field 3 72-96	72	96	7.7	2.84	35.6	3.0	21.1	10.6	11.7	62	22	16	SL
H06120087-015	Field 4 0-6	0	6	7.6	0.58	60.8	0.71	4.14	1.32	1.18	19	49	32	SiCL
H06120087-016	Field 4 6-12	6	12	7.5	0.44	45.9	0.92	3.15	1.03	1.33	31	45	24	L
H06120087-017	Field 4 12-24	12	24	7.6	2.66	41.9	4.4	18.1	7.15	15.8	44	36	20	L
H06120087-018	Field 4 24-36	24	36	7.6	2.85	46.0	4.3	18.9	8.21	15.8	34	43	23	L
H06120087-019	Field 4 36-48	36	48	7.7	3.75	39.8	6.5	18.4	14.8	26.5	45	35	20	L
H06120087-020	Field 4 48-72	48	72	7.5	2.89	38.0	4.1	19.6	10.6	16.1	50	31	19	L
H06120087-021	Field 4 72-96	72	96	7.7	2.87	29.4	3.2	20.4	9.36	12.2	68	21	11	SL
H06120087-022	Field 5 0-6	0	6	7.6	2.74	60.9	3.0	19.5	9.04	11.3	22	44	34	CL
H06120087-023	Field 5 6-12	6	12	7.7	4.65	49.0	9.3	18.1	13.0	36.8	32	42	26	L
H06120087-024	Field 5 12-24	12	24	8.1	6.73	55.2	15	15.6	21.3	65.6	27	43	30	CL
H06120087-025	Field 5-24-36	24	36	8.1	6.43	44.8	14	16.3	23.5	62.2	45	32	23	L
H06120087-026	Field 5 36-48	36	48	7.9	4.92	34.5	9.4	18.0	16.4	38.8	62	22	16	SL
H06120087-027	Field 5 48-72	48	72	7.8	3.96	30.0	6.1	21.3	13.9	25.6	76	14	10	SL
H06120087-028	Field 5 72-96	72	96	7.3	3.28	45.9	8.8	9.45	9.13	26.8	45	31	24	L
H06120087-029	Field 6 0-6	0	6	7.5	1.45	64.2	3.4	7.30	2.54	7.56	13	52	35	SiCL
H06120087-030	Field 6 6-12	6	12	7.7	4.51	61.1	9.9	17.7	10.4	37.0	14	54	32	SiCL
H06120087-031	Field 6 12-24	12	24	8.1	7.37	64.2	16	18.2	20.4	69.7	9	54	37	SiCL
H06120087-032	Field 6 24-36	24	36	8.2	7.36	51.4	16	18.1	26.5	76.0	32	43	25	L
H06120087-033	Field 6 36-48	36	48	8.1	7.28	38.7	15	18.4	23.0	67.4	54	31	15	SL
H06120087-034	Field 6 48-72	48	72	7.9	4.53	37.2	6.9	18.3	18.1	29.4	65	21	14	SL
H06120087-035	Field 6 72-96	72	96	7.7	3.75	34.3	5.2	20.5	13.3	21.5	63	23	14	SL
H06120087-036	Field 7 0-6	0	6	7.6	0.77	65.1	1.7	4.03	1.59	2.91	11	49	40	SiC
H06120087-037	Field 7 6-12	6	12	7.6	3.05	54.0	5.2	16.7	8.86	18.4	29	42	29	CL
H06120087-038	Field 7 12-24	12	24	8.0	6.21	44.0	13	20.2	16.7	54.8	42	38	20	L
H06120087-039	Field 7 24-36	24	36	8.0	6.24	35.3	12	20.4	18.7	52.9	54	29	17	SL
H06120087-040	Field 7 36-48	36	48	7.9	5.09	37.2	8.4	17.0	18.3	35.5	62	24	14	SL

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LABORATORY ANALYTICAL REPORT

Client: Yates Petroleum Corp
Project: CottonWood Creek Section 20 Analysis
Workorder: H06120087

Report Date: 01/03/07
Date Received: 12/10/06

		Analysis		pH-SatPst	COND	Percent Sat	SAR	Ca-SatPst	Mg-SatPst	Na-SatPst	Sand	Silt	Clay	Texture
		Units		s_u_	mmhos/cm	%	unitless	meq/l	meq/l	meq/l	%	%	%	unitless
Sample ID	**Client Sample ID**	**Up**	**Low**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**
H06120087-041	Field 7 48-72	48	72	7.9	4.92	41.3	6.9	20.7	18.2	30.5	57	28	15	SL
H06120087-042	Field 7 72-96	72	96	7.9	4.20	31.7	6.8	19.2	14.4	27.7	69	8	23	SCL

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LABORATORY ANALYTICAL REPORT

Client: Yates Petroleum Corp
Project: CottonWood Creek Section 20 Analysis
Workorder: H06120087

Report Date: 01/03/07
Date Received: 12/10/06

		Analysis		OM-WB	CEC	Lime	Na-Ext	Exch Na	ESP
		Units		%	meq/100g	%	meq/100g	meq/100g	%
Sample ID	Client Sample ID	Up	Low	Results	Results	Results	Results	Results	Results
H06120087-001	Field 2 0-6	0	6	3.05	32.8	5.6	0.49	0.4	1.3
H06120087-002	Field 2 6-12	6	12		23.5	5.3	0.50	0.4	1.9
H06120087-003	Field 2 12-24	12	24		24.2	5.5	2.49	1.6	6.8
H06120087-004	Field 2 24-36	24	36		27.5	5.0	5.80	3.9	14
H06120087-005	Field 2 36-48	36	48		25.4	5.2	7.80	5.1	20
H06120087-006	Field 2 48-72	48	72		29.3	5.0	8.48	6.1	21
H06120087-007	Field 2 72-96	72	96		23.8	4.8	4.51	3.0	13
H06120087-008	Field 3 0-6	0	6	3.27	36.5	5.5	4.91	3.0	8.3
H06120087-009	Field 3 6-12	6	12		22.3	4.7	6.46	3.9	17
H06120087-010	Field 3 12-24	12	24		11.2	3.7	4.07	2.1	19
H06120087-011	Field 3 24-36	24	36		29.2	5.6	8.74	5.9	20
H06120087-012	Field 3 36-48	36	48		18.9	4.6	1.57	1.1	5.9
H06120087-013	Field 3 48-72	48	72		18.8	4.5	2.32	1.6	8.3
H06120087-014	Field 3 72-96	72	96		14.9	6.7	1.39	1.0	6.5
H06120087-015	Field 4 0-6	0	6	2.62	36.7	5.4	0.48	0.4	1.1
H06120087-016	Field 4 6-12	6	12		30.2	5.4	0.55	0.5	1.6
H06120087-017	Field 4 12-24	12	24		22.7	4.6	1.98	1.3	5.8
H06120087-018	Field 4 24-36	24	36		24.8	5.0	2.48	1.8	7.1
H06120087-019	Field 4 36-48	36	48		20.3	4.5	3.37	2.3	11
H06120087-020	Field 4 48-72	48	72		21.3	4.6	2.17	1.6	7.3
H06120087-021	Field 4 72-96	72	96		13.6	5.7	1.49	1.1	8.3
H06120087-022	Field 5 0-6	0	6	3.37	38.2	5.1	2.37	1.7	4.4
H06120087-023	Field 5 6-12	6	12		24.7	5.2	5.34	3.5	14
H06120087-024	Field 5 12-24	12	24		28.8	5.5	12.4	8.8	30
H06120087-025	Field 5-24-36	24	36		18.5	4.9	9.64	6.9	37
H06120087-026	Field 5 36-48	36	48		18.1	5.6	3.67	2.3	13
H06120087-027	Field 5 48-72	48	72		14.3	3.9	2.21	1.4	10
H06120087-028	Field 5 72-96	72	96		32.3	5.5	4.29	3.1	9.5
H06120087-029	Field 6 0-6	0	6	3.40	41.0	5.1	1.96	1.5	3.6
H06120087-030	Field 6 6-12	6	12		39.8	5.5	7.08	4.8	12
H06120087-031	Field 6 12-24	12	24		40.4	5.6	13.8	9.4	23
H06120087-032	Field 6 24-36	24	36		33.4	5.3	10.8	6.9	21
H06120087-033	Field 6 36-48	36	48		19.7	4.6	6.67	4.1	21
H06120087-034	Field 6 48-72	48	72		17.0	4.0	2.55	1.5	8.6
H06120087-035	Field 6 72-96	72	96		18.0	4.4	2.00	1.3	7.0
H06120087-036	Field 7 0-6	0	6	3.05	46.7	4.9	1.28	1.1	2.3
H06120087-037	Field 7 6-12	6	12		36.5	4.8	4.15	3.2	8.7
H06120087-038	Field 7 12-24	12	24		25.6	4.8	7.79	5.4	21
H06120087-039	Field 7 24-36	24	36		19.1	6.2	4.79	2.9	15
H06120087-040	Field 7 36-48	36	48		18.0	4.4	3.72	2.4	13

LABORATORY ANALYTICAL REPORT

Client: Yates Petroleum Corp
Project: CottonWood Creek Section 20 Analysis
Workorder: H06120087

Report Date: 01/03/07
Date Received: 12/10/06

		Analysis		OM-WB	CEC	Lime	Na-Ext	Exch Na	ESP
		Units		%	meq/100g	%	meq/100g	meq/100g	%
Sample ID	Client Sample ID	Up	Low	Results	Results	Results	Results	Results	Results
H06120087-041	Field 7 48-72	48	72		14.7	4.9	3.08	1.8	12
H06120087-042	Field 7 72-96	72	96		9.31	4.6	2.51	1.6	18