Section 20 Compliance Analysis for Discharges by the Williams Cedar Draw Project to the Middle Prong Wild Horse Creek Drainage, Campbell County, Wyoming

REPORT SUMMARY

INTRODUCTION

- This report presents an evaluation of the proposed coalbed natural gas (CBNG) produced water discharge into the Middle Prong Wild Horse Creek drainage at the Williams Production RMT Company (Williams) Cedar Draw Project in Campbell County, Wyoming.

- This report includes an evaluation of the soils and vegetation of the Spellman property owned by Bobbie and Becky Spellman.

- The analysis presented herein will demonstrate that any discharge made by Williams into the Middle Prong Wild Horse Creek drainage will not result in a measurable decrease in crop or livestock production.

EXISTING DOWNSTREAM IRRIGATION

Location of Proposed Discharges

- Produced water discharges in the Cedar Draw Project will ultimately occur to 23 reservoirs constructed in various ephemeral draws tributary to the Middle Prong Wild Horse Creek.

- All discharges to stream channels will occur as overflow from the constructed reservoirs. The stream channels ultimately flow into Middle Prong Wild Horse Creek.

Location of Existing Downstream Irrigation

- The Spellman field is located along the Middle Prong Wild Horse Creek in Sections 31 and 32 of Township 54 North, Range 75 West, approximately 10 miles east-southeast of Arvada, Wyoming. The field in question comprises approximately 75 acres. At the time of the site investigation no human-made mechanism to divert water for the purposes of irrigation (e.g., spreader dikes, flood irrigation, or sprinkler irrigation systems) existed.

Irrigation Practices

- A stream flow of 13 cfs is required to cause water to overtop the channel and spread across the Spellman field.

Irrigated Crops

- Western wheatgrass and bluegrass would be considered important forage species, meaning that they are the only dominant species for which a rancher would manage.

Western wheatgrass has a threshold soil salt tolerance levels of 6.0 dS/m, and bluegrass species have a threshold salt tolerance of 10 to 12 dS/m

EFFLUENT WATER QUALITY

Expected Produced Water Quality

- The expected EC of the Cedar Draw Project produced water to be discharged is 2.1 dS/m with an SAR ranging from 21 to 22.

Expected Blended Water Quality

- Produced water will be discharged into constructed reservoirs and be subject to dilution from stormwater runoff and precipitation. A mixing analysis determined that a storm event with a two-year return interval would result in the greatest percentage, 3.3%, of CBNG water to reach the irrigated field on the Spellman property. With 3.3% CBNG produced water, the water reaching the Spellman field would have an EC of 1.2 dS/m and an SAR of 0.84.

- To provide the most conservative estimate of water quality that may reach the Spellman field a separate mixing analysis was performed for Reservoir 43-31, which is located immediately upstream of the middle portion of the field. The mixing analysis that only examined Reservoir 43-31 determined that overflow and runoff containing 78% CBNG produced water would reach the Spellman irrigated field from a two-year storm event. With 78% CBNG produced water, the blended water reaching the Spellman field would exhibit an EC of 1.9 dS/m and an SAR of 8.8.

Irrigation Water Suitability Assessment

Salinity

- The estimated EC of the blended water that will reach the Spellman field in the Cedar Draw Project is 1.2 dS/m. The estimated EC of the blended water from Reservoir 43-31 that will reach the Spellman field is 1.9 dS/m. With respect to EC, the blended irrigation water can be used to irrigate crops that are, at a minimum, moderately tolerant with no restrictions.

Sodicity

- The blended water quality for the Cedar Draw Project is estimated to have an EC of 1.2 dS/m and SAR of 0.84 and the blended water from Reservoir 43-31 that will reach the Spellman field is estimated to have an EC of 1.9 dS/m and SAR of 8.8. Based on the Hanson et al. (1999) guidelines, long-term irrigation using these waters would result in "no reduction in infiltration" due to sodium adsorption.

Livestock Watering Suitability

- The CBNG produced water quality data meets all livestock drinking water guidelines and will not cause a measurable decrease in livestock production.

COMPLIANCE WITH DEFAULT EC AND SAR EFFLUENT LIMITS

- Based on western wheatgrass, with a soil salinity threshold of 6 dS/m, the resulting default effluent limits for EC and SAR would be 4.0 dS/m and 25, respectively. The expected EC and SAR of the unblended produced water to be discharged is 2.1 dS/m for EC and ranges from 21 to 22 for SAR. The expected discharge water quality will comply with the default limits for EC and SAR.

IRRIGATED SOILS IMPACT ASSESSMENT

Soil Mapping Units and General Description

- Soils at the Spellman field are mapped as a Haverdad-Boruff complex, 0 to 3% slopes, by the Campbell County, Wyoming, Northern Part Soil Survey.

- Haverdad soils have soil EC levels ranging from 0 to 8 dS/m throughout the profile, with EC levels as high as 16 dS/m in areas with irrigation. These soils are mainly used for grazing with principal native vegetation being big sagebrush, western wheatgrass, *greasewood*, and annual grasses and forbs.

- Boruff soils have EC levels that range from 0 to 4 dS/m in the surface horizons, and from 2 to 8 dS/m in the subsurface horizons. The average ESP ranges from 0 to 10%, with some subsurface horizons having ESP values in excess of 10%.

Soil Physical Conditions

- Clay mineralogy in the surface soil samples (0 to 6 inch) was generally dominated by smectite clay minerals in the Spellman field.
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Soil Chemical Conditions

- In the Spellman field, soil sample pH within the plant root zone (0 to 48 inches) ranges from 7.1 to 8.1 and is considered in the ideal range.

- The EC ranged from 4.8 to 13 dS/m in the soil samples collected from within the crop root zone (0 to 48 inches) at the Spellman field. All EC levels in the soil samples were greater than 4 dS/m, indicating saline soil conditions.

- Calculated average root zone EC for the Spellman field is 10. This is a high soil EC level and would define these soils as saline. It would be expected that only salt tolerant plant species could be grown in these soils.

- Soil samples from within the crop root zone (0 to 48 inches) at the Spellman field exhibit SAR values ranging from 6.2 to 23, with an average SAR to a depth of 48 inches of 19. The Spellman field would be considered saline-sodic.

Assessment of Potential Soil Impacts

- The estimated EC of the blended water that will reach the Spellman fields is 1.2 dS/m, or 1.9 dS/m when considering the more conservative estimate of water reaching the Spellman field from Reservoir 43-31. With an average root zone EC in the soils sampled at the Spellman field of 10 dS/m (Table 3), the blended water will not result in an increase in soluble salt concentration beyond the natural levels in the soil.

- With respect to sodicity, the expected SAR of the blended water to reach the Spellman fields is 0.84, or 8.8 when considering the more conservative estimate of water reaching the Spellman field from Reservoir 43-31. With an average soil SAR value (to a depth of 48 inches) of 19 in the Spellman field, long-term use of the blended water will not cause a measurable increase in average SAR. Therefore, it is expected that there would be no measurable decrease in hydraulic function of the soil and any related decrease in crop production.

SECTION 20 COMPLIANCE SUMMARY

- This report demonstrates that any discharge made by Williams into the Middle Prong Wild Horse Creek will not result in a measurable decrease in crop or livestock production, as required by Chapter 1, Section 20 of the Wyoming Water Quality Rules and Regulations.

- The CBNG produced water quality meets all livestock watering requirements, as specified in WYDEQ (2004) and National Academy of Sciences (1972 and 1974), and will not result in a measurable decrease in livestock production.

- With respect to the irrigation uses, discharge of CBNG produced water from the Cedar Draw Project will not result in a measurable decrease in crop production on the Spellman field. This statement of compliance is based on the following three analyses: (1) irrigation suitability assessment of the blended water that will reach the Spellman field (see Section 3); (2) comparison of probable EC and SAR effluent limits with expected discharge water quality (see Section 4); and, (3) analysis of potential crop and soil impacts due to sustained irrigation with expected blended water quality (see Section 5).

Section 20 Compliance Analysis for Discharges by the Williams Cedar Draw Project to the Middle Prong Wild Horse Creek Drainage, Campbell County, Wyoming

Prepared for:

Williams Production RMT Company
Gillette, Wyoming

Prepared by:

KC Harvey, LLC
Soil and Water Resources Consultants
Bozeman, Montana

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1.0 INTRODUCTION

This report presents an evaluation of the proposed coalbed natural gas (CBNG) produced water discharge into the Middle Prong Wild Horse Creek drainage at the Williams Production RMT Company (Williams) Cedar Draw Project in Campbell County, Wyoming. The purpose of this evaluation is to demonstrate whether the proposed discharge will be in compliance with Chapter 1, Section 20 of the Wyoming Water Quality Rules and Regulations. This report includes an evaluation of the soils and vegetation of the Spellman property owned by Bobbie and Becky Spellman. According to research conducted by Williams, no other landowners downstream of their proposed discharge conduct irrigation using water from Middle Prong Wild Horse Creek or from downstream of the confluence with Wild Horse Creek to the main stem of the Powder River.

Chapter 1, Section 20 of the Wyoming Water Quality Rules and Regulations state that,

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

The analysis presented herein will demonstrate that any discharge made by Williams into the Middle Prong Wild Horse Creek drainage will not result in a measurable decrease in crop or livestock production. To accomplish this, soil scientists, agronomists and range ecologists from KC Harvey, LLC conducted a site investigation of the Spellman property that included a vegetation survey and soil sampling and analysis. Crop species present at the site were then researched to determine salinity tolerance levels. Soil sampling results were also used to gauge potential impacts from the potential presence of produced water.

Regulatory guidance for conducting the following Section 20 analysis is based on (1) the information requirements stipulated in Item 18 of the Wyoming DEQ NPDES Application for Permit to Discharge Produced Water, Revised December 19, 2003; (2) current Section 20 analysis policy stipulated by the Wyoming DEQ flowchart entitled "Section 20 Irrigation Study Process;" and (3) the current draft Section 20 Agricultural Use Protection Policy dated August 2005.

The main body of this report is comprised of seven sections, including this introduction (Section 1). Section 2 describes the location of proposed outfalls, the presence of irrigated fields located downstream of the discharge points, irrigation practices and irrigated crops. The expected quality of the produced water discharge is summarized in Section 3 including an assessment of CBNG produced water quality for livestock watering and irrigation. Section 4 compares the expected discharge water quality with expected electrical conductivity (EC) and sodium adsorption ratio (SAR) effluent limits. Section 5 presents an assessment of the potential impacts to irrigated soils.

Lastly, a summary statement regarding compliance with the Section 20 narrative standard is presented in Section 6. References cited throughout the report are provided in Section 7. Figures, tables, photos, and appendices are located at the rear of the report.

2.0 EXISTING DOWNSTREAM IRRIGATION

2.1 Location of Proposed Discharges

Produced water discharges in the Cedar Draw Project will ultimately occur to 23 reservoirs constructed in various ephemeral draws tributary to the Middle Prong Wild Horse Creek. Nine of the 23 reservoirs currently have WYPDES permits. The Middle Prong Wild Horse Creek flows northwest for approximately 16 miles to the confluence with the main stem of Wild Horse Creek. From that point, Wild Horse Creek flows approximately eight river miles to the confluence with the Powder River near Arvada, Wyoming. The Middle Prong Wild Horse Creek is an ephemeral stream flowing for brief periods during spring runoff and after thunderstorms.

The 23 permitted and proposed WYPDES discharge outfalls are located in Sections 31 and 32 in Township 54 North, Range 75 West, and in Sections 6, 7, 8, 16, 17, 18, 20, 21, 22, 27, 28, 33, and 34 of Township 53 North, Range 75 West (Figure 1). All discharges to stream channels will occur as overflow from the constructed reservoirs. The stream channels ultimately flow into Middle Prong Wild Horse Creek.

2.2 Location of Existing Downstream Irrigation

Research conducted by Williams in preparation of WYPDES permit applications for the Cedar Draw Project revealed that passive irrigation for limited hay production and associated livestock grazing occurs downstream of the proposed discharge locations on land owned by Bobbie and Becky Spellman. The Spellman field is located along the Middle Prong Wild Horse Creek in Sections 31 and 32 of Township 54 North, Range 75 West (Figure 2), approximately 10 miles east-southeast of Arvada, Wyoming. The field in question comprises approximately 75 acres. At the time of the site investigation no human-made mechanism to divert water for the purposes of irrigation (e.g., spreader dikes, flood irrigation, or sprinkler irrigation systems) existed. No other irrigation practices or irrigated fields were identified between the discharges and the confluence with the main stem of Wild Horse Creek and the subsequent confluence of Wild Horse Creek with the Powder River.

2.3 Irrigation Practices

Current irrigation practices within the Spellman field are passive and infrequent. No structures or mechanisms have been constructed to collect, divert, or apply water for irrigation. A road with a culvert was constructed across the middle of the field and is not meant to serve as an irrigation dike (Photo 1). Debris jams within the channel provide other opportunities for passive irrigation (Photo 2).

The stream channel is fairly incised at the upper and lower reaches of the Spellman field, requiring as much as 287 cubic feet per second (cfs; Photo 3), before stream water can overtop the channel and spread out into the field (Johnson, 2005). The lowest flows required to spread water across the irrigated field occurs immediately downstream of the road, where the channel is less incised (Photo 4). A stream flow of 13 cfs will cause water to overtop the channel and spread across the field immediately downstream of the road (Johnson, 2005).

Because of the passive nature of the irrigation, no clear standard irrigation practices are followed. The timing, frequency, and duration of irrigation are controlled by the climatic conditions that produce sufficient stream flow to overtop the channel.

2.4 Irrigated Crops

An inventory of the vegetation present in the Spellman field was conducted by Jerry Gladson on July 12 and 13, 2005, and a report summarizing his results is attached in Appendix A. Mr. Gladson is an agricultural consultant out of Buffalo, Wyoming and an expert on the native range vegetation of the Powder River Basin. He was formerly a District Conservationist with the Soil Conservation Service.

Mr. Gladson divided the Spellman field into four sampling units (A, B, C, and D), walked straight-line transects (shown in Figure 2) perpendicular to the stream channel in each sampling unit, and made ocular estimates of the species present and their abundance. At least three transects were completed in each sampling unit. Abundance estimates from each sampling unit were averaged to produce a list of dominant vegetation species at the Spellman field (Table 1). All transect vegetation percentages and a complete species list are provided in Mr. Gladson's report (Appendix A).

From the dominant plant species listed in Table 1, western wheatgrass (*Pascopyrum smithii*) and bluegrass (*Poa spp.*) would be considered important forage species, meaning that they are the only dominant species for which a rancher would manage. Western wheatgrass has a threshold soil salt tolerance level of 6.0 dS/m, and bluegrass species have a threshold salt tolerance of 10 to 12 dS/m (Table 1; Bridger Plant Materials Center, 1996). The threshold salt tolerance level of a plant is the maximum soil salinity level at which plant yield is not reduced (Hanson et al., 1999). Salt tolerance levels are determined experimentally by comparing plant growth or yield under varying soil salinity levels. The salt tolerance of a plant is affected by many conditions, including climate, soils, plant age, and salt type, and is not an exact value. Plant salt tolerance levels are generally expressed as an average root zone salinity, meaning they refer to the weighted soil salinity level of the entire rooting depth.

3.0 EFFLUENT WATER QUALITY

3.1 Expected Produced Water Quality

Expected CBNG produced water quality to be discharged from the Cedar Draw Project in accordance with a WYPDES permit is provided in Table 2. The water quality data provided in

Table 2 is from existing Williams' outfalls and wells. The outfall, WY0050865, provides information on the Anderson/Werner coal seams and is located in Section 16, Township 53 North, Range 75 West, and was sampled by Williams on June 23, 2005. The well producing from the Gates coal seam is located in Section 13, Township 53 North, Range 76 West, and was sampled by Williams on March 8, 2005. Energy Laboratories, Inc., Gillette, Wyoming, conducted all water quality analyses. Williams has indicated that these data are representative of the expected produced water quality that will be generated at the Cedar Draw Project area. The expected EC of the produced water to be discharged is 2.1 dS/m with an SAR ranging from 21 to 22 (Table 2).

3.2 Expected Blended Water Quality

Produced water will be discharged into constructed reservoirs and be subject to dilution from stormwater runoff and precipitation. Therefore, a mixing analysis was performed by WWC Engineering, Sheridan, Wyoming, in May, 2005, to provide an estimate of the quality of the water that will overflow the Williams constructed reservoirs and reach the Spellman irrigated area. The complete analysis prepared by WWC Engineering is attached as Appendix B. The mixing analysis determined that a storm event with a two-year return interval would result in the greatest percentage, 3.3%, of CBNG water to reach the irrigated field on the Spellman property. Based on WWC Engineering's calculations, with 3.3% CBNG produced water, the water reaching the Spellman field would have an EC of 1.2 dS/m and an SAR of 0.84 (Table 2).

Upon further discussion with WWC Engineering it was learned that a separate mixing analysis was performed for Reservoir 43-31 (Lindy, 2005). Reservoir 43-31 is located in Section 31 of Township 54 North, Range 75 West, in an unnamed tributary located immediately upstream of the middle portion of the Spellman field. To provide the most conservative estimate of water quality that may reach the Spellman field, the separate mixing analysis for Reservoir 43-31 will be considered. The mixing analysis that only examined Reservoir 43-31 determined that overflow and runoff containing 78% CBNG produced water would reach the Spellman irrigated field from a two-year storm event. Based on WWC Engineering's calculations, with 78% CBNG produced water, the blended water reaching the Spellman field would exhibit an EC of 1.9 dS/m and an SAR of 8.8 (Table 2).

3.3 Irrigation Water Suitability Assessment

The blended water quality that is expected to overflow the constructed reservoirs is assessed herein for irrigation suitability. In addition, to provide the most conservative assessment, the blended water quality from the closest located reservoir to the Spellman field, Reservoir 43-31, will also be assessed for irrigation suitability.

To assess the water for irrigation, three specific areas are addressed: salinity, sodicity, and specific ion toxicity (Ayers and Westcot, 1985; and Hanson et al., 1999). It should be noted that these water quality parameters and their potential impact to soils and crops are considered to be chronic rather than acute parameters (i.e., potential impacts to soil and crops occur after long-term use of a specific irrigation water).

3.3.1 Salinity

The salinity of the irrigation water, measured as the electrical conductivity (EC), does not directly impact soil physical properties. Instead, salts make it more difficult for plants to extract water from the soil and are a concern if the crop yield is affected. 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 the irrigation water during long-term use of the water. The concentration of salts in a soil due to the use of saline irrigation water can be managed, within reason, by way of agronomic leaching (i.e., applying more water to the soil than is required for evaporation and plant transpiration) to prevent the concentration of salts in the root zone.

Guidelines for interpretations of water quality for irrigation (Ayers and Westcot, 1985; Hanson et al., 1999) indicate that water with an EC less than 0.7 deciSiemens per meter (dS/m) will be suitable for all crops without restriction. Water exhibiting an EC between 0.7 and 3.0 dS/m can be used to irrigate moderately tolerant crops with no restrictions, while water with an EC between 3.0 and 6.0 dS/m can be used to irrigate salt-tolerant crops with no restrictions on use. For waters with an EC greater than 6.0 dS/m, only salt-tolerant crops should be considered.

The estimated EC of the blended water that will reach the Spellman field in the Cedar Draw Project is 1.2 dS/m (Table 2). The estimated EC of the blended water from Reservoir 43-31 that will reach the Spellman field is 1.9 dS/m. With respect to EC, the blended irrigation water can be used to irrigate crops that are, at a minimum, moderately tolerant with no restrictions.

3.3.2 Sodicity

Irrigation water with an elevated sodium adsorption ratio can result in changes to the physical structure of a soil and its hydraulic properties such as infiltration and permeability. The infiltration and permeability of soils 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 use of irrigation water that is high in sodium and low in calcium and magnesium. Consequently, the ratio of sodium to calcium and magnesium ions in water is an important property affecting the infiltration and permeability hazard. The water quality index used to measure the hazard related to sodium abundance or sodicity is the sodium adsorption ratio or SAR.

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

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

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

The SAR formula indicates that if calcium and magnesium concentrations are low and sodium is high, then the SAR will be high. Conversely, if calcium and/or magnesium concentrations increase relative to sodium, then SAR will decrease.

Clay minerals in soils are negatively charged and consequently attract ions with a positive charge such as sodium, calcium and magnesium. When sodium comprises more than about 15% of the exchangeable ions, the clays can begin to repel one another causing the soil structure to degrade. The continued swelling and dispersion of clay minerals and subsequent degradation of soil structure can reduce the rate of water infiltrating the soil and the permeability of water through the soil. In general, soils with moderately high, to high, clay contents are at higher risk. Further, those soils where swelling type clays (i.e., smectite clays) are abundant are at higher risk.

What is not apparent from the SAR formula is the fact that the higher the salinity of the water, the higher the SAR can be without impacting soil structure and impairing soil infiltration and permeability. Put another way, for a given SAR, infiltration rates generally decrease as salinity (measured by the EC) decreases. The changes in soil infiltration and permeability occur at varying SAR levels, higher if the salinity is high, and lower if the salinity is low. Therefore, in order to evaluate the sodicity risk of irrigation water, the EC must be considered.

The blended water quality for the Cedar Draw Project is estimated to have an EC of 1.2 dS/m and SAR of 0.84 and the blended water from Reservoir 43-31 that will reach the Spellman field is estimated to have an EC of 1.9 dS/m and SAR of 8.8 (Table 2). Based on the Hanson et al. (1999) guidelines presented above, long-term irrigation using these waters would result in "no reduction in infiltration" due to sodium adsorption.

3.3.3 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 results in damage to the plant. Given that woody crop species are not typically grown for agricultural production in the Middle Prong Wild Horse 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). Boron was not estimated in the mixing analysis that produced the blended water quality data but was analyzed for in the Gates produced water sampling (Table 2). Boron was not detected in the Gates CBNG produced water sample representative of the Cedar Draw Project and therefore will not be a limitation to crop growth.

3.4 Livestock Watering Suitability

To assess the Cedar Draw Project water quality for use in livestock production, the expected CBNG produced water quality data (Table 2) were compared to Wyoming Water Quality Rules and Regulations (WYDEQ, 2004) and suggested guidelines for levels of toxic substances in livestock drinking water (National Academy of Sciences, 1972 and 1974). The CBNG produced water quality was used in the livestock watering suitability assessment because unblended produced water may be available to stock prior to any mixing. As can be seen in Table 2, the CBNG produced water quality data meets all livestock drinking water guidelines and will not cause a measurable decrease in livestock production.

4.0 COMPLIANCE WITH DEFAULT EC AND SAR EFFLUENT LIMITS

At the time of this writing, the Wyoming DEQ is revising its policy for implementing the Section 20 narrative water quality standard for protecting agricultural uses. The revised draft Agricultural Use Protection Policy (August 2005) would, among other things, stipulate the methods for deriving default effluent limits for EC and SAR in WYPDES permitted CBNG produced water discharges. In summary, the default effluent limits for EC and SAR would be derived as follows:

1. Identify the presence of any irrigated fields downstream of proposed outfalls prior to the confluence with the main stem (i.e., the Powder River).

2. Collect basic data regarding location of irrigation diversions, crops grown, and published EC tolerance levels for crops grown.

3. Identify the most sensitive crop species and convert the published soil EC tolerance level for that crop to an irrigation tolerance level based on the equation $EC_{soil} = 1.5 \times EC_{irrigation\ water}$ (Ayers and Westcot, 1984).

4. Establish an SAR limit based on the EC limit to achieve "no reduction in infiltration" using the relationship between EC and SAR represented by the equation $SAR < (7.10 \times EC_{irrigation\ water}) - 2.48$ (Hanson et al., 1999).

5. Compare the expected effluent quality with the default limits for EC and SAR. If the expected EC and SAR levels in the effluent exceed the default EC and SAR limits, then refine effluent limits based on actual or calculated background irrigation water quality or via a site-specific soil-crop-water study to demonstrate "no harm" to existing crop production.

The process described above for deriving default limits for EC and SAR was followed for the expected CBNG produced water quality described above in Section 3.1. As discussed above in Section 2.4, the most saline-sensitive important forage species found in the Spellman field is western wheatgrass. This forage species is expected to produce 100 % yields in soils with an average root zone EC up to 6.0 dS/m (Bridger Plant Materials Center, 1996). Therefore, based on the soil-water EC relationship described above in item 3, dividing 6.0 dS/m by 1.5 yields an EC effluent limit of 4.0 dS/m. Based on the EC-SAR relationship described above in item 4, for an irrigation water EC value of 4.0 dS/m, an SAR level of 25 or less would result in no reduction in soil infiltration (i.e., no impact to soil structure and hydraulic function). The resulting default effluent limits for EC and SAR would then be 4.0 dS/m and 25, respectively. The expected EC and SAR of the unblended produced water to be discharged, as described above in Section 3.1 is 2.1 dS/m for EC and ranges from 21 to 22 for SAR. In this case, the expected discharge water quality will comply with the default limits for EC and SAR.

5.0 IRRIGATED SOILS IMPACT ASSESSMENT

5.1 Purpose

Based on the analysis presented above in Section 4, the expected discharge water quality will comply with expected default EC and SAR effluent limits contained in the WYPDES permit for the Cedar Draw Project. In addition to this analysis, a site-specific assessment of the potential impact to irrigated soils was conducted. The purpose of the following assessment is to determine whether or not the expected effluent discharged to Middle Prong Wild Horse Creek will negatively impact the irrigated soils identified on the Spellman property.

5.2 Soil Sampling and Analysis Methods

On July 12 and 13, 2005, the Spellman field was inspected and soil samples were collected as part of the Section 20 Analysis. Soil samples were collected using a Giddings Probe (Giddings Machine Company, Windsor, Colorado) operated by InterMountain Laboratories, Inc., Sheridan, Wyoming. The Spellman field was divided into four sampling units and subsamples were collected from six to ten locations within each sampling unit. At each subsample 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 60, and 60 to 96 inches. All subsample locations were located using a handheld global positioning system (GPS) unit and are shown on Figure 2. The subsamples were composited, by depth, for each sampling unit and delivered to Energy Laboratories Inc., Helena, Montana, for analysis of pH, electrical conductivity (EC), sodium adsorption ratio (SAR), exchangeable sodium percentage (ESP), dissolved calcium, dissolved magnesium, dissolved sodium, exchangeable sodium, saturation percentage, texture (percent sand, silt, and clay), cation exchange capacity (CEC), lime content, organic matter content (surface samples only), and clay mineralogy (surface samples only). Analysis results for the chemical and physical properties from each sampling unit were averaged together to create an overall field value and are provided in Tables 3 and 4. The original laboratory analytical reports are provided in Appendix C.

5.3 Soil Mapping Units and General Description

Soils at the Spellman field are mapped as a Haverdad-Boruff complex, 0 to 3% slopes, by the Campbell County, Wyoming, Northern Part Soil Survey (NRCS, 2005; Figure 2). The official series descriptions for the Haverdad and Boruff series are included in Appendix C. Haverdad soils are described as very deep, well drained soils that formed in stratified alluvium on flood plains and low terraces. Textures range from loam to clay loam, with clay fractions ranging from 15 to 35%. Permeability ranges from 4.2 to 14 micrometers per second. They have a mixed mineralogy class and have soil EC levels ranging 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 a year, with over half the precipitation occurring in April, May, and June. Flooding in Haverdad soils occur for brief periods during spring runoff and after thundershowers. These soils are mainly used for grazing with principal native vegetation being big sagebrush, western wheatgrass, greasewood, and annual grasses and forbs (National Cooperative Soil Survey, 2002).

Boruff soils are described as very deep, poorly and somewhat poorly drained soils formed in alluvium on flood plains and low stream terraces. Textures range from loam to clay, with clay fractions ranging from 35 to 60%. Thin, stratified layers of sandier material are commonly found in the subsurface horizons. Permeability ranges from 0.42 to 1.4 micrometers per second. Boruff soils have a smectitic mineralogy class. Soil EC levels range from 0 to 4 dS/m in the surface horizons, and from 2 to 8 dS/m in the subsurface horizons. The average ESP ranges from 0 to 10%, with some subsurface horizons having ESP values in excess of 10%. Boruff soils receive an average of 14 inches of precipitation annually, half of which falls as rain or snow from March through June. Flooding occurs for very brief or brief periods during prolonged, high intensity storms in the spring and early summer. Boruff soils are primarily used as rangeland and wildlife habitat with principal native vegetation being green needlegrass, bearded wheatgrass, slender wheatgrass, western wheatgrass, cottonwoods, Indian saltgrass, alkai sacaton, sedges, and willows (National Cooperative Soil Survey, 2003).

5.4 Soil Physical Conditions

Soil physical properties affect aeration rates, water infiltration, water storage, and movement of water through the soil profile. Soil textures in the samples collected from the Spellman field include silty clay loam and clay loam. Clay percentages range from 30 to 36% in all horizons sampled at the Spellman field (Table 4). Clay mineralogy in the surface soil samples (0 to 6 inch) was generally dominated by smectite clay minerals. Clay mineralogy may be important when considering the effects of irrigating with sodic water sources. Smectitic clays are considered shrink-swell clays, that expand upon wetting and shrink after drying, and may be more affected by sodic water irrigation.

5.5 Soil Chemical Conditions

5.5.1 Soil pH

pH is perhaps the most important chemical characteristic of the soil and indicates the intensity of the acidic or basic condition of the 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 crops. As the pH increases above or decreases below this ideal range, the availability of phosphorus, calcium, magnesium, iron, manganese, zinc, copper, cobalt, and boron may be limiting. In the Spellman field, soil sample pH within the plant root zone (0 to 48 inches) ranges from 7.1 to 8.1 (Table 3) and is considered in the ideal range.

5.5.2 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 highly tolerant plants (e.g., 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 typical because arid regions are subject to high evaporation rates, thus allowing salt concentration to occur (Soil Improvement Committee, California Plant Health Association, 2002).

The EC ranged from 4.8 to 13 dS/m in the soil samples collected from within the crop root zone (0 to 48 inches) at the Spellman field. All EC levels in the soil samples were greater than 4 dS/m, indicating saline soil conditions.

An average root zone EC was calculated to better gauge long-term plant response to soil salinity. Plants respond to the average root zone salinity, rather than to the highest or lowest measured soil EC, as long as there is sufficient water available in the lower salinity horizons of the rooting zone (Hanson, et al, 1999). To calculate average root zone EC, the grass species present at the Spellman field were assumed to have an average root zone depth of 48 inches, and a 40-30-20-10 water use pattern. The 40-30-20-10 water use pattern simply means that the plant extracts 40% of its required water from the top quarter of the rooting zone, 30% from the second quarter, 20% from the third quarter, and 10% from the bottom quarter of the rooting zone (Ayers and Westcot, 1986). With an average root zone depth of 48 inches, each quarter of the root zone would equal 12 inches. Therefore to calculate average root zone EC, the following formula was used:

$$\text{Average Root Zone EC} = (EC_{0\text{-}12} \times 0.4) + (EC_{12\text{-}24} \times 0.3) + (EC_{24\text{-}36} \times 0.2) + (EC_{36\text{-}48} \times 0.1)$$

where, $EC_{0\text{-}12}$ refers to the EC measured in the collected soil samples at the 0 to 12 inch depth increment. For the Spellman field, 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 root zone calculation. The calculated average root zone EC for the Spellman field is 10 dS/m (Table 3). This is a high soil EC level and would define these soils as saline. It would be expected that only salt tolerant plant species could be grown in these soils. Possibly the vegetation growing in this field is more salt tolerant than expected.

5.5.3 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 sodium tend to disperse soil particles thereby sealing the soil. The result can produce hard surface crusts, reduced infiltration rates, 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) of more than 15 or a sodium adsorption ratio (SAR) of at least 13, an EC less than 4 dS/m, and a pH between 8.5 and 10 (U.S. Salinity Laboratory Staff, 1954; Soil Science Society of America, 2001).

Soil SAR is calculated using the same formula as that for determining water quality SAR, provided above in Section 3.1.2. To measure the concentrations of calcium, magnesium, and sodium in a soil sample, a saturated paste is prepared and allowed to equilibrate for approximately eight hours. Soil water from the sample is then extracted and analyzed for the calcium, magnesium, and sodium ion concentrations. Typical SAR values for soils in northeastern Wyoming range from less than 1 up to about 5.

The ESP of a soil is the "percentage of the cation exchange capacity of a soil occupied by sodium ions (Soil Science Society of America, 2001)." Every soil has a definite capacity to adsorb the positively charged constituents of dissolved salts, such as calcium, magnesium, potassium, sodium, etc. This is termed the cation exchange capacity (CEC). The various adsorbed cations (such as calcium and sodium) can be exchanged one for another and the extent of exchange depends upon their relative concentrations in the soil solution (dissolved), the ionic charge (valence), the nature and amount of other cations, etc. ESP is, accordingly, the amount of adsorbed sodium on the soil exchange complex expressed in percent of the cation exchange capacity in milliequivalents per 100 grams of soil (meq/100 g). Thus,

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

Typical ESP values for soils in northeastern Wyoming range from less than 1% up to about 5%.

Soil samples from within the crop root zone (0 to 48 inches) at the Spellman field exhibit SAR values ranging from 6.2 to 23 (Table 3), with an average SAR to a depth of 48 inches of 19 (Table 3). The same soil samples exhibit ESP values ranging from 3.9 to 12% (Table 3), with an average ESP to a depth of 48 inches of 9.0%. When considering the SAR data the Spellman field would be considered saline-sodic. However, if one considers the ESP data, the Spellman field is approaching saline-sodic conditions. Saline-sodic soils are soils with SAR levels above 13 or ESP values greater than 15%, 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, the Spellman field is naturally limited for crop production because of the enriched salinity and sodicity.

Another index of potentially dispersed sodic soil conditions is the saturation percentage. Saturation percentage is the amount of water, by weight, necessary to form a minimally flowable mud from dry soil materials and is used as an index of the swelling capacity and dispersive condition of the soil (Merrill, et al., 1987). In general, a saturation percentage of less than 80% indicates non-dispersed, non-sodic soil conditions. With a saturation percentage range of 52 to 69%, all samples from the Spellman field have saturation percentages below 80% (Table 4). Possibly the high salinity levels in the Spellman soils are keeping the clay particles flocculated and preventing dispersion.

5.6 Assessment of Potential Soil Impacts

Based on the soil sampling and analysis data described above in Section 5.5, the soils within the Spellman field are substantially saline and sodic, i.e., they exhibit naturally elevated EC and SAR/ESP values throughout the soil profile. Regardless, based on the site inspection, this field appears to be functioning relatively well with respect to crop production and soil hydraulics. The estimated EC of the blended water that will reach the Spellman field is 1.2 dS/m, or 1.9 dS/m when considering the more conservative estimate of water reaching the Spellman field from Reservoir 43-31 (Table 2). With an average root zone EC in the soils sampled at the Spellman field of 10 dS/m (Table 3), the blended water will not result in an increase in soluble salt concentration beyond the natural levels in the soil.

With respect to sodicity, the expected SAR of the blended water to reach the Spellman field is 0.84, or 8.8 when considering the more conservative estimate of water reaching the Spellman field from Reservoir 43-31 (Table 2). With an average soil SAR value (to a depth of 48 inches) of 19 in the Spellman field, long-term use of the blended water will not cause a measurable increase in average SAR. Therefore, it is expected that there would be no measurable decrease in hydraulic function of the soil and any related decrease in crop production.

6.0 SECTION 20 COMPLIANCE SUMMARY

Williams is proposing to discharge CBNG produced water to 14 additional reservoirs in various tributaries of Middle Prong Wild Horse Creek. Nine reservoirs in the project area have already been permitted. Discharge to the tributaries will occur as overflow from all 23 of the constructed reservoirs and will ultimately flow into Middle Prong Wild Horse Creek and run through the Spellman property. The Spellman field is passively irrigated with no mechanical irrigation structures in place. Any irrigation that occurs does so once the water level is high enough to overflow the stream channel. The Spellman field comprises approximately 75 acres and is used for hay production and livestock grazing. The most important forage species that is dominant in the Spellman field is western wheatgrass.

This report demonstrates that any discharge made by Williams into the Middle Prong Wild Horse Creek will not result in a measurable decrease in crop or livestock production, as required by Chapter 1, Section 20 of the Wyoming Water Quality Rules and Regulations. The CBNG produced water quality meets all livestock watering requirements, as specified in WYDEQ (2004) and National Academy of Sciences (1972 and 1974), and will not result in a measurable decrease in livestock production.

With respect to the irrigation uses, discharge of CBNG produced water from the Cedar Draw Project will not result in a measurable decrease in crop production on the Spellman field. This statement of compliance is based on the following three analyses: (1) irrigation suitability assessment of the blended water that will reach the Spellman field (see Section 3); (2) comparison of probable EC and SAR effluent limits with expected discharge water quality (see Section 4); and, (3) analysis of potential crop and soil impacts due to sustained irrigation with expected blended water quality (see Section 5).

The salinity, sodicity, and specific ion toxicity of the blended water were evaluated to determine irrigation suitability. The blended water can be used to irrigate crops that are, at a minimum, moderately salt tolerant, with no restrictions. Long-term irrigation using the blended water would result in no reduction in infiltration due to the sodicity of the water. And, no specific ion toxicity issues are expected based on the water quality analysis data. Therefore the blended water that will reach the Spellman field is suitable for irrigation.

The probable or "default" limits for EC and SAR are based on the maximum soil EC before yield is reduced in the most saline-sensitive forage species found in the Spellman field, western wheatgrass. The EC limit is then used to establish an SAR limit that when related to the EC of the water will result in "no reduction in infiltration" according to the scientific literature (Hanson et al., 1999). It has been demonstrated that the expected quality of the CBNG discharge water from the Cedar Draw Project will comply with the default EC and SAR limits.

In addition to the demonstration of providing a suitable source of irrigation water and compliance with probable effluent limits, a site-specific assessment of potential impact to the irrigated soils was conducted. The soil sampling and analysis program demonstrated that the soils within the Spellman field are appreciably saline and sodic. This analysis indicates that sustained application of blended CBNG produced water to the field will not negatively affect the current salinity and sodicity condition of the soils. Therefore, any measurable decrease in crop production is not expected.

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Table 1. Dominant vegetation species, with their threshold soil salinity tolerance levels, at the Spellman field on the Middle Prong Wild Horse Creek in the Williams Cedar Draw Project. [1]

Dominant Vegetation Species		Composition (%)	Threshold Soil Salinity Tolerance[2] (dS/m)
Common Name	**Scientific Name**		
Upland:			
Western wheatgrass	*Pascopyrum smithii*	45	6
Saltgrass	*Distichtis stricta*	10	n/a
Bluegrass	*Poa spp.*	5	10 - 12
Riparian:			
Sedge	*Carex spp.*	30	n/a
Prairie cordgrass	*Spartina pectinata*	20	n/a
Western wheatgrass	*Pascopyrum smithii*	5	6
Saltgrass	*Distichtis stricta*	5	n/a
Foxtail barley	*Hordeum jubatum*	20	n/a

Notes:

1 A vegetation survey was conducted by Mr. Jerry Gladson, Agricultural Consultant, Buffalo, Wyoming, on July 12-13, 2005. The vegetation survey was conducted by walking straight-line transects perpendicular to the stream channel and making ocular estimates of the species present and their abundance.

2 Threshold salinity tolerance levels are given in deciSiemens per meter and are from Bridger Plant Materials Center (1996). N/a means that no tolerance level was available.

Table 2. Livestock watering standards[1], expected CBNG produced water quality[2], and estimated blended water quality[3] for the Williams Cedar Draw Project.[4]

Analyte	Units	Livestock Watering Standards	Anderson/Werner WY0050865	Gates	Blended Water Reaching the Spellman Field[5]	Blended Water from Reservoir 43-31Reaching the Spellman Field[6]
pH	*s.u.*	6.5 to 9	7.6	7.5	-	-
Electrical Conductivity (EC)	*dS/m*	7.5	2.1	2.1	1.2	1.9
Total Dissolved Solids (TDS)	*mg/L*	5000	1370	1340	-	-
Sodium Adsorption Ratio (SAR)		-	21	22	0.84	8.8
Anions						
Bicarbonate	*mg/L*	-	1540	1500	-	-
Chloride	*mg/L*	2000	9.0	13	-	-
Fluoride	*mg/L*	2.0	*0.60*	*0.60*	-	-
Sulfate	*mg/L*	3000	<1	<1	-	-
Cations						
Calcium	*mg/L*	-	23	23	382	104
Magnesium	*mg/L*	-	14	12	100	33
Sodium	*mg/L*	-	512	517	71	400
Metals[7]						
Arsenic	*µg/L*	200	<0.2	<0.1	-	-
Boron	*µg/L*	5000	-	*nd*	-	-
Cadmium	*µg/L*	50	<0.1	<0.1	-	-
Chromium	*µg/L*	1000	-	*nd*	-	-
Copper	*µg/L*	500	3	11	-	-
Lead	*µg/L*	100	<2	<2	-	-
Mercury	*µg/L*	10	<0.06	<0.06	-	-
Selenium	*µg/L*	50	<5	<5	-	-
Zinc	*µg L*	24000	<10	<10	-	-

Notes:

1 Livestock watering standards are from WYDEQ (2004) and National Academy of Sciences (1972 and 1974).

2 The Anderson/Werner data are from a nearby existing Williams outfall (WY0050865) in Section 16, Township 53 North, Range 75 West, in the North Cedar Draw POD. Except for italicized numbers, the results are from sampling conducted on June 23, 2005. Italicized results are from sampling conducted on September 9, 2004. Except for the italicized values, the Gates data are from a nearby existing Williams well in Section 13, Township 53 North, Range 76 West, in the Cedar Draw State POD, which was sampled on March 8, 2005. Italicized values are from a nearby Gates/Wall well in Township 53 North, Range 76 West and are listed to demonstrate expected levels of fluoride, boron, and chromium. All water samples were analyzed by Energy Laboratories, Inc., Gillette, Wyoming.

3 Blended water quality was estimated by WWC Engineering in a report dated May 19, 2005, and is included as Appendix B.

4 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.

5 Water quality data are based on WWC Engineering's mixing analysis for when the greatest amount of CBNG water, 3.3%, would reach the Spellman field. The greatest amount of CBNG water would reach the Spellman field during a storm event with a 2-year return interval.

6 Blended water quality data from Reservoir 43-31 were calculated by WWC Engineering as the most conservative estimate of CBNG water to reach the Spellman field. The mixing analysis assumes water from only Reservoir 43-31, the closest upstream reservoir to the Spellman field, would reach the field. During a storm event with a 2-year return interval, water reaching the Spellman field from an unnamed tributary of Middle Prong Wild Horse Creek (where Reservoir 43-31 is located) would contain 78.4% CBNG produced water (Johnson, 2005).

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

Table 3. Soil chemical analysis results for the Spellman field on the Middle Prong Wild Horse Creek in the Williams Cedar Draw Project[1,2].

Site	Depth	pH	Electrical Conductivity at 25° C (EC)	Average Root Zone EC[3]	Calcium	Magnesium	Sodium	Sodium Adsorption Ratio (SAR)	Average SAR to a depth of 48 inches[4]	Cation Exchange Capacity (CEC)	Exchangeable Sodium	Exchangeable Sodium Percentage (ESP)	Average ESP to a depth of 48 inches[4]	Lime as $CaCO_3$
	inches	s.u.	dS/m		meq/L					meq/100 g		%		
Spellman Field	0 to 6	7.1	4.8	10	25	17	28	6.2	19	38	1.5	3.9	9.0	3.8
	6 to 12	7.7	8.4		24	29	76	15		31	2.4	7.8		4.3
	12 to 24	8.1	13		23	48	139	23		32	3.1	9.7		4.5
	24 to 36	8.1	13		23	49	131	22		33	3.8	12		4.7
	36 to 48	7.9	11		24	43	111	19		32	2.8	8.8		4.4
	48 to 60	7.9	11		24	45	100	17		30	2.9	10		4.3
	60 to 96	7.6	8.7		22	33	65	12		30	2.2	7.4		3.9

Notes:

1 Samples were collected on July 12-13, 2005 by KC Harvey, LLC using a Giddings Probe operated by InterMountain Laboratories, Inc., Sheridan, Wyoming. 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, % =

3 Average root zone EC was calculated assuming an average root zone of 48 inches and a 40-30-20-10 water use pattern with the following formula: Average Root Zone EC = $(EC_{0\text{-}12} \times 0.4) + (EC_{12\text{-}24} \times 0.3) + (EC_{24\text{-}36} \times 0.2) + (EC_{36\text{-}48} \times 0.1)$ (Ayers and Westcot, 1986). The EC results for the 0 to 6 and 6 to 12 inch depths were averaged together to derive the 0 to 12 inch EC.

4 Average SAR 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 each 12 inch depth increment to a depth of 48 inches.

Table 4. Soil physical analysis results for the Spellman field on the Middle Prong Wild Horse Creek in the Williams Cedar Draw Project[1,2].

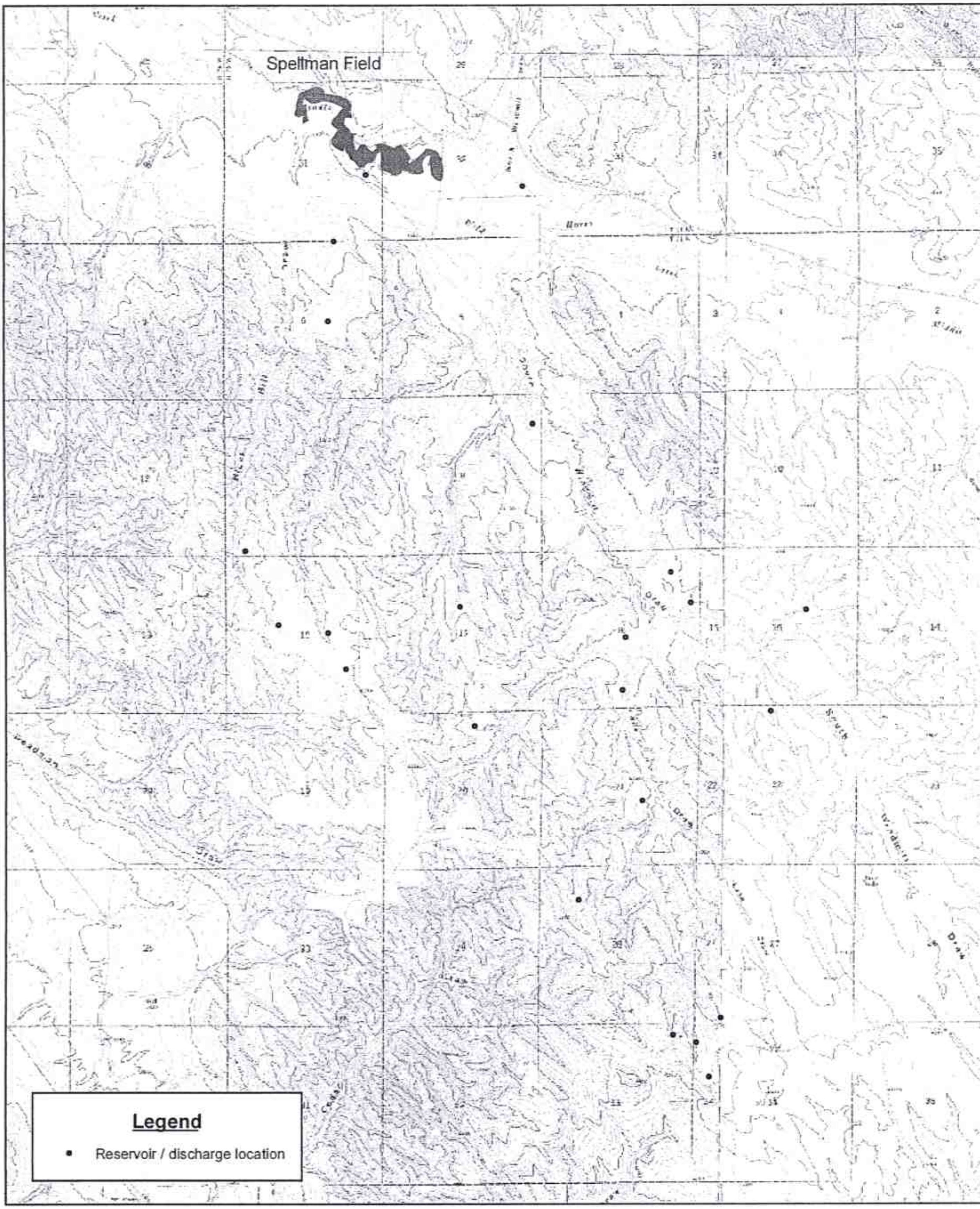
Site	Depth	Texture	Sand	Silt	Clay	Surface Clay Mineralogy[3]	Saturation Percentage	Organic Matter
	inches			%			%	
Spellman Field	0 to 6	Silty Clay Loam	14	51	36	39% Smectite, 30% Illite, 31% Kaolinite	69	4.4
	6 to 12	Clay Loam	23	47	30		57	-
	12 to 24	Silty Clay Loam	18	49	34		62	-
	24 to 36	Silty Clay Loam	20	48	32		60	-
	36 to 48	Clay Loam	21	47	33		60	-
	48 to 60	Clay Loam	27	42	31		56	-
	60 to 96	Clay Loam	35	41	33		52	-

Notes:

1 Samples were collected on July 12-13, 2005 by KC Harvey, LLC using a Giddings Probe operated by InterMountain Laboratories, Inc., Sheridan, Wyoming. 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.



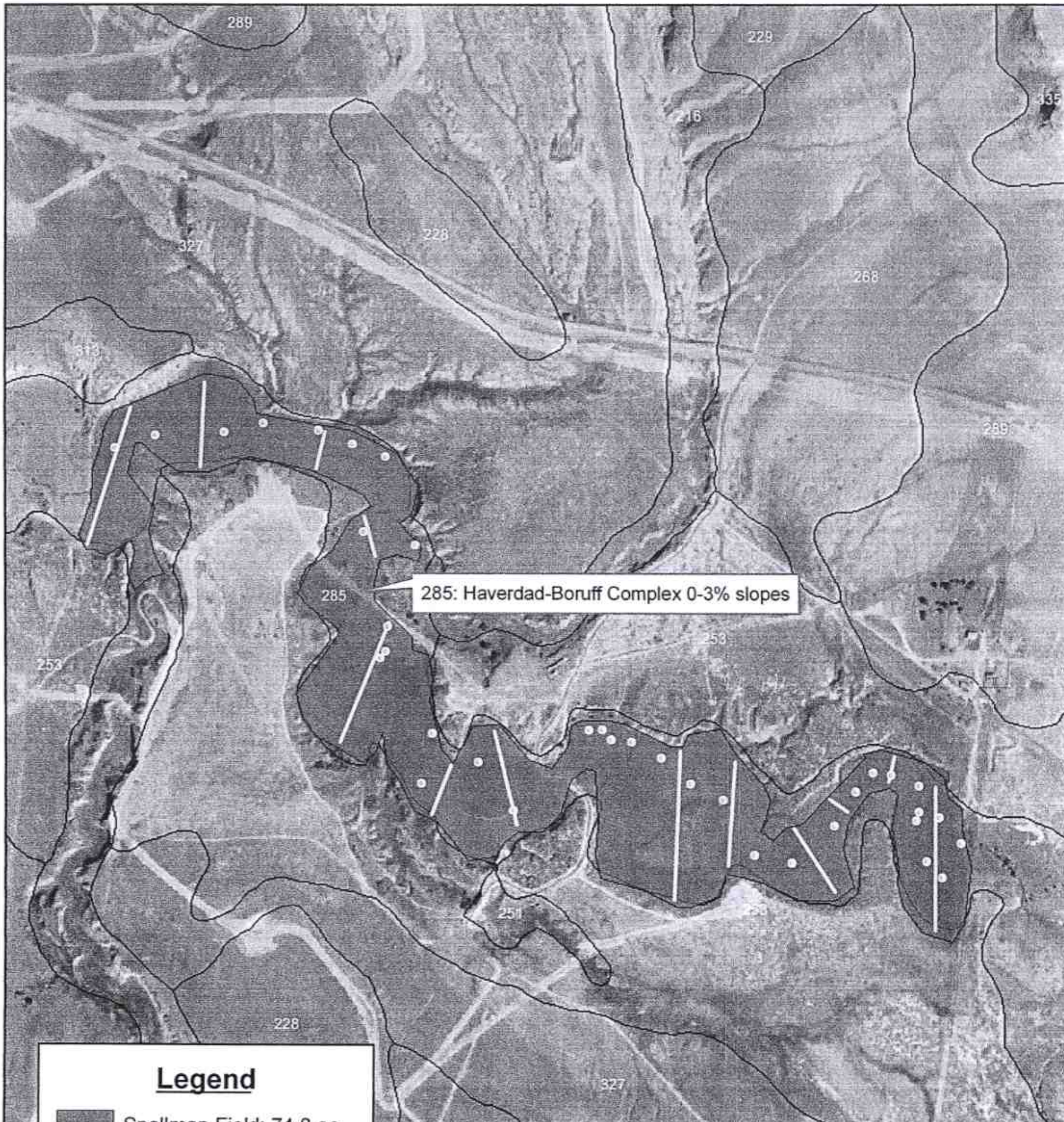
Williams Production RMT

Scale: 1:50,000

Figure 1: Proposed/permitted reservoir locations/discharge points in the Cedar Draw Project.

Drawn By CSM

KC HARVEY, LLC
SOIL AND WATER RESOURCE CONSULTANTS



Williams Production RMT	Scale: 1:9,000		KC HARVEY, LLC SOIL AND WATER RESOURCE CONSULTANTS
Figure 2: Spellman field with soil sampling locations, vegetation transects and NRCS mapped soil boundaries.	Drawn By CSM		

Photo 1. Road with culvert that crosses the Spellman field.

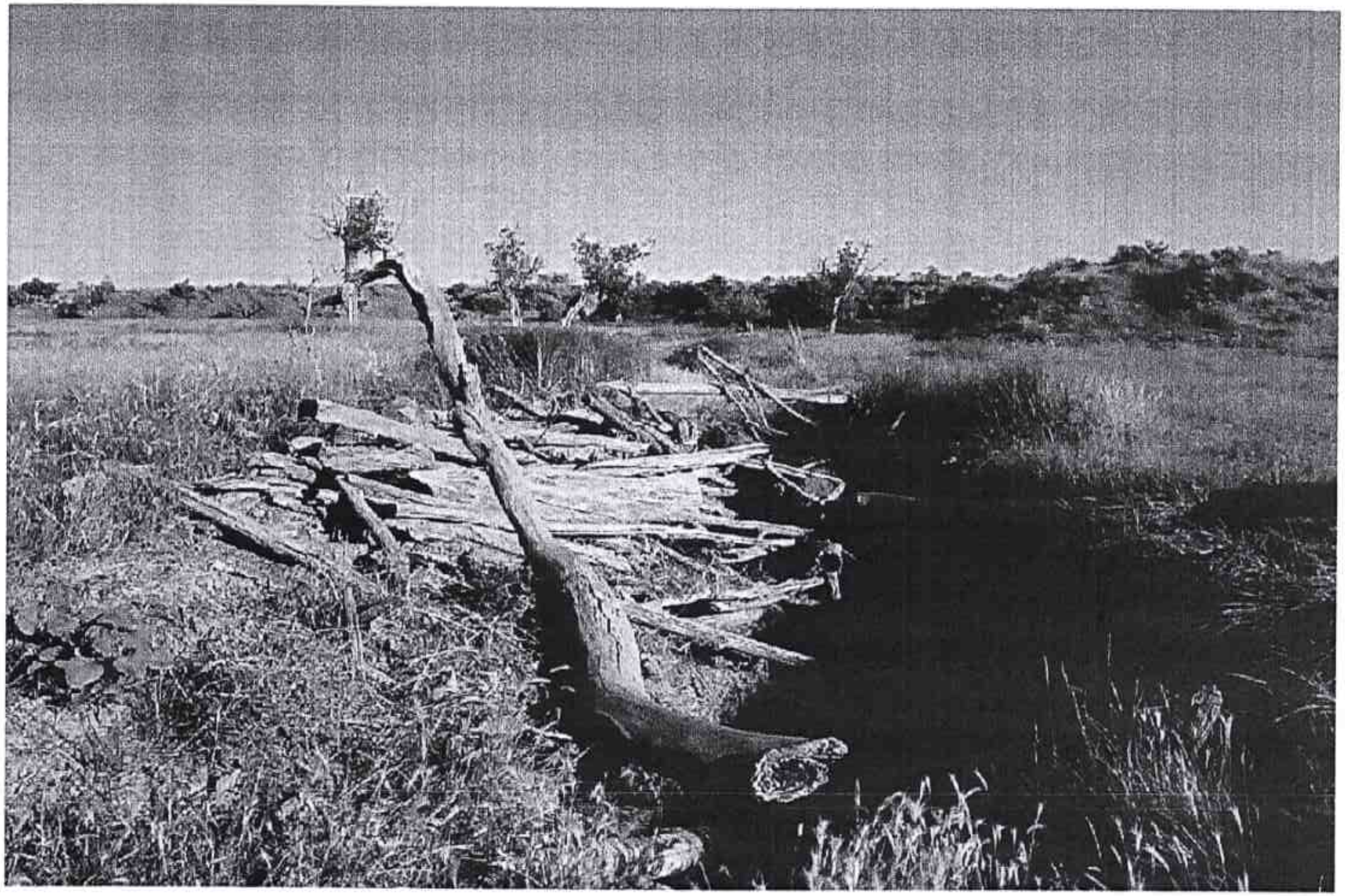


Photo 2. Debris jam in the Spellman field that provides passive irrigation.

Photo 3. Incised Middle Prong Wild Horse Creek channel in the Spellman field. At this location, the highest flow is required to initiate irrigation (287 cfs) at the Spellman property.

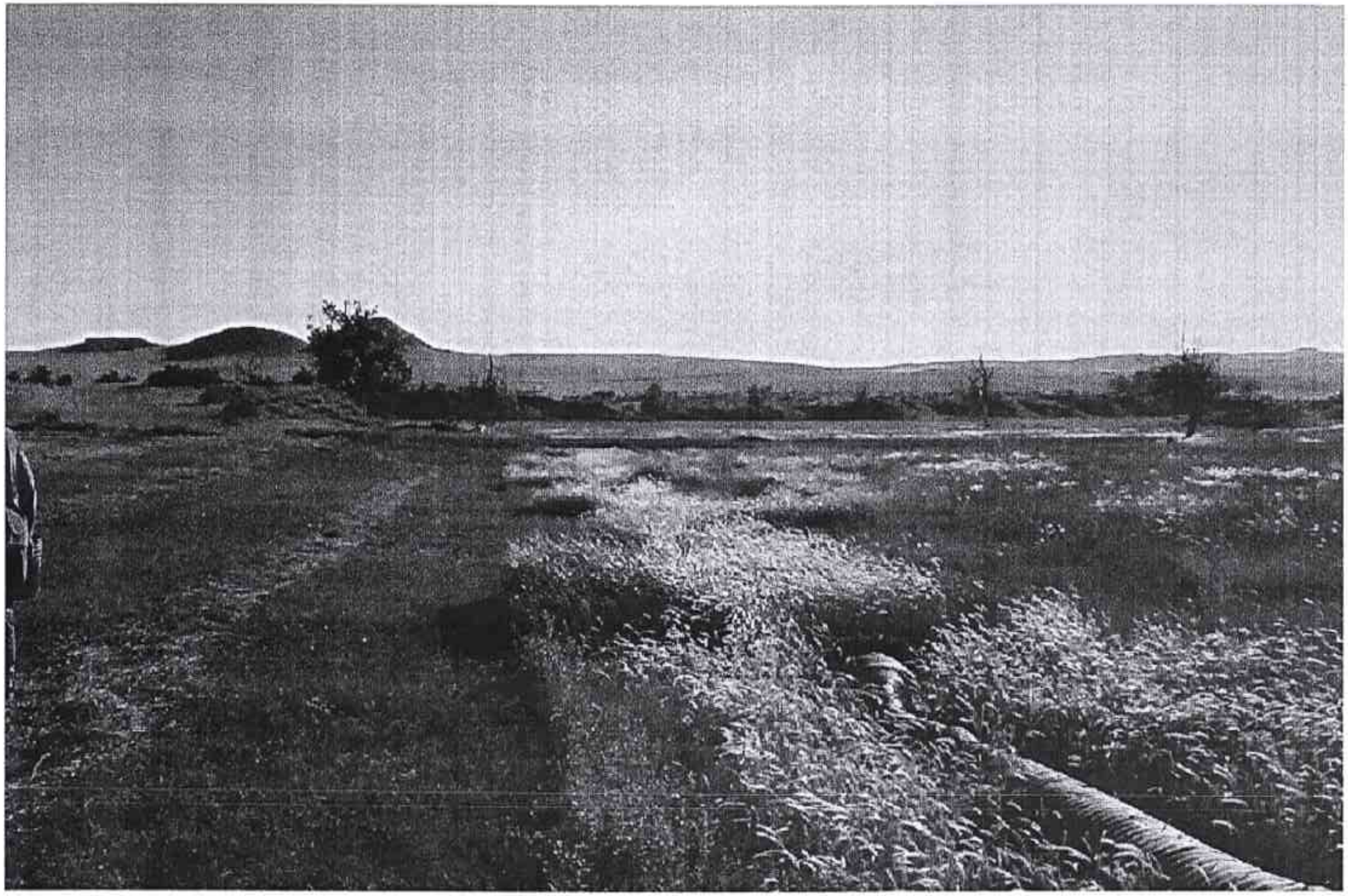


Photo 4. Spellman field where the Middle Prong Wild Horse Creek channel is less incised. At this location, the lowest flow is required to initiate irrigation (13 cfs) at the Spellman property.

Appendix A

Jerry D. Gladson
200 Vandyke Street
Buffalo, WY 82834

August 7, 2005

Dina E. Brown
KC Harvey, LLC
233 Edelweiss Drive, Suite 11
Bozeman, MT 59718

VEGETATIVE INVENTORY: SPELLMAN IRRIGATION FIELDS
Cedar Draw Units
Williams Production RMT Company
Middle Prong Wild Horse Creek Section 20 Analysis

Dear Ms. Brown:

INTRODUCTION

The purpose of the vegetative inventory is to identify the vegetative species present in the various fields and rank the dominance of the major species.

Each field was inventoried by walking a series of random paths through the fields. These paths are identified as transects on the attached worksheets. The vegetation along the paths was identified and an ocular percentage estimate make of the dominant species. A minimum of two transects were completed on each field.

On fields that had been hayed, transects were completed on vegetation outside the mowed area as well as inside the mowed area. Where it had been hayed, residual vegetation was used to complete the inventory.

No attempt was made to identify the individual species of the genus Carex, Salix and Poa. Plant species exist that were not encountered along the transects, however, they do not makeup a significant part of the plant community and represent less than 1% of the composition.

The two noxious weeds, Field bindweed and Leafy spurge, were present at various locations. In conversation with Mr. Spellman, landowner, he indicated he has been aggressively spraying Leafy spurge with chemicals, primarily "Round-up", in an attempt to reduce or eliminate Leafy spurge.

<u>SPELLMAN IRRIGATION</u>
<u>CEDAR DRAW UNITS</u>

<u>SPELLMAN FIELD "A"</u>

This area is a typical draw bottom field. The Middle Prong Creek riparian area varies from 10 to 20 feet in width. The dominant vegetation in this area is Carex, spp at 50%, Prairie cordgrass at 15% and Foxtail barley at 10%. Some Russian olive and old Plains cottonwood trees are present. The upland area on either side of the riparian varies from 15 feet to 350 feet wide. The dominant vegetation in these areas is Western wheatgrass at 45% and Saltgrass at 20%. The primary shrub species include Silver sagebrush and Greasewood. All areas show evidence of overflow and the vegetation is healthy with moderate vigor.

The following is a chart of percentages of the species represented in each area of each transect. The "X" indicates the presence of the species in the transect. The "XX" indicates the presence of the species at a level of one and three percent of the composition. Together the "X" and "XX" make up the balance of the composition.

	TRANSECT 1			TRANSECT 2					TRANSECT 3	
	Area 1	Area 2	Area 3	Area 1	Area 2	Area 3	Area 4	Area 5	Area 1	Area 2
Western Wheatgrass	80		45	20	45		40		5	50
Six-Week fescue	XX									
Kochia	XX		X	X	X		X	X	X	X
Curlycup gumweed	XX		XX		X		X	10		
Saltgrass	X	XX	10	50	30	10	30		5	
Carex spp		65		X	X	50		50	40	10
Foxtail barley		5		5	5	10		10	10	X
Silver sagebrush		XX			X		X		X	5
Intermediate wheatgr.		XX				X	5		X	XX
Prairie cordgrass		20				10	5	5	20	10
Green needle grass			10							
Leafy spurge										X
Field bindweed			X							

SPELLMAN-FIELD A										
Page 2										
	Area 1	Area 2	Area 3	Area 1	Area 2	Area 3	Area 4	Area 5	Area 1	Area 2
Alfalfa			XX							X
Smooth bromegrass			XX							
Canada wildrye			XX						X	
Redroot pigweed			X							
Poa spp	5	XX	5	10	5	X	X	10	XX	5
Downy bromegrass										XX
Japanese bromegrass	5		10	X	X		5		X	XX
Clasping pepperweed			X				X		X	XX
Crested wheatgrass			X				X			
Western salsify			X							
Russian thistle			X							
Canada thistle			X			X				
Prickly lettuce				X	X					
Russian olive						X			X	
Greasewood										5
Two grove milk vetch							X			
Timothy									X	

Field A consists of 3 transects. Transect 1 consists of three areas. Area 1 is a 75 foot upland, Area 2 is a 15 foot riparian, Area 3 is a 340 foot upland. Transect 2 consists of 5 areas. Area 1 is a 15 foot upland, Area 2 is a 10 foot overflow, Area 3 is a 10 foot riparian, Area 4 is a 100 foot upland and Area 5 is a 10 foot overflow. Transect 3 consists of 2 areas. Area 1 is a 20 foot riparian and Area 2 is a 100 foot upland.

All distances are estimates.

SPELLMAN IRRIGATION
CEDAR DRAW UNITS

SPELLMAN FIELD "B"

The riparian area in this field varies from 10 feet to 30 feet in width. The dominant vegetation is Prairie cordgrass at 30%, Carex spp. At 20% , Foxtail barley at 15% and Saltgrass at 10%. The upland areas varies from 75 feet to 600 feet wide. The dominant vegetation if Western wheatgrass at 50%, Intermediate wheatgrass at 20% and Poa spp at 5%. Small swale areas that occur are dominated with Saltgrass. Older Plains cottonwood and Russian olive trees occur in this area. The primary shrub species is Silver sagebrush.
All areas are subject to flooding. The vegetation is healthy with moderate vigor.

The following is a chart of percentages of the species represented in each area of each transect. The "X" indicates the presence of the species in the transect. The "XX" indicates the presence of the species at a level between 1 and 3% of the composition. Together the "X" and "XX" make up the balance of the composition.

	TRANSECT 1						TRANSECT 2			TRANSECT 3		
	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 1	Area 2	Area 3	Area 1	Area 2	Area 3
Western wheatgrass	50	5	60	40	50	70	35	10	60	45	10	20
Greasewood		30										
Carex spp		X	X	10			XX	40	XX		10	
Prarie cordgrass		25	XX					30		5	30	
Foxtail barley		15		50				5			30	5
Quackgrass						X		X	X	X		X
Kochia	X	X	X		15		XX		5	5		X
Japanese brome grass	XX		XX		10	XX	XX		XX	X		5
Clasping pepper weed	X		XX		5	X	XX		XX	X		X
Intermediate wheat grass						5	25	10	10	30		40
Timothy	X											
Silver sagebrush	10		10	X			5		XX	X		

SPELLMAN – FIELD “B”

	TRANSECT 1						TRANSECT 2			TRANSECT 3		
	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 1	Area 2	Area 3	Area 1	Area 2	A-3
Canada wild rye		5										
Poa spp	5		5			5	5	X	5		5	10
Leafy spurge	X		X	5			X	X			X	X
Saltgrass		10							X	5	15	X
Downy brome	XX		XX		5		XX	X	XX	X		X
Marshelder	XX	X			X		X					
Alfalfa	10		X			X	X		X			5
Green needle grass	5		5		10	10	10			XX		5
Crested wheat grass			X					X	X			
Yellow sweet clover				X							X	
Western yarrow							X					
Western salsify					X							

Field B consists of 3 Transects. Transect 1 consists of six areas; Area 1 is an 80 foot upland, Area 2 is a 30 foot riparian, Area 3 is a 100 foot upland, Area 4 is a 6 foot overflow, Area 5 is a 150 foot upland and Area 6 is a 190 foot upland. Transect 2 consists of three areas; Area 1 is a 20 foot upland, Area 2 is a 20 foot riparian and Area 3 is a 200 foot upland. Transect 3 consists of 3 areas; Area 1 is a 76 foot upland, Area 2 is a 10 foot riparian and Area 3 is a 600 foot upland. All distances are estimates.

SPELLMAN IRRIGATION
CEDAR DRAW UNITS

SPELLMAN FIELD "C"

This field had been swathed prior to the vegetative inventory. The riparian area varies from 10 feet to 20 feet in width. The dominant vegetation is Foxtail barley at 40%, Prairie cordgrass at 15%, and Carex spp at 15%. The upland areas, which vary from 100 feet to 400 feet in width, is dominated by Western wheat grass at 45%. This field has considerable annual and perennial weeds. Some old Plains cottonwood trees occur. Primary shrub species include Silver sagebrush and Greasewood. All areas are subject to flooding.

The following is a chart of percentages of the species represented in each area of each transect. The "X" indicates the presence of the species in the transect. The "XX" indicates the presence of the species at a level between 1 and 3% of the composition. Together the "X" and "XX" make up the balance of the composition.

	TRANSECT 1			TRANSECT 2			TRANSECT 3			TRANSECT 4	
	Area 1	Area 2	Area 3	Area 1	Area 2	Area 3	Area 1	Area 2	Area 3	Area 1	Area 2
Western Wheat Gr.	35		45	50	20	45	45	20	60	50	10
Silver sagebrush						X				X	
Japanese Brome	5			XX		X	X		X	XX	
Rocky Mtn. Bee plant						X				X	
Downey brome	XX			XX		X	X		X	XX	
Crested wh. grass	5								5	5	
Salt grass		XX			XX			5		X	X
Kochia	10	X	5	5		5	5		5	X	X
Bindweed	X		X	X			X		X	X	
Skelton weed	X		X				X			X	
Alfalfa	X			X			5		5	5	
Marshelder	X		X				X			XX	
Smooth brome	15			XX			5				
Common rye	20										

SPELLMAN FIELD "C"

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	TRANSECT 1			TRANSECT 2			TRANSECT 3			TRANSECT 4	
	Area 1	Area 2	Area 3	Area 1	Area 2	Area 3	Area 1	Area 2	Area 3	Area 1	Area 2
Prairie cord grass		15			10			15			20
Green needle grass		15								5	
Carex spp.		10	5	5	15			15			30
Intermediate wheatgrass					5		5				
Greasewood			X						5		
Curley cup gumweed			X	X		10			X		
Leafy spurge		X				X		X	X	X	X
Bearded wheatgrass			10	10		10	10		5	5	5
Timothy				XX			5				
Curly dock					X						
Prickly lettuce						X					
Slender wheatgrass							10	5			
Dandelion										X	
Yellow sweet clover							X				
Western salsify							X				X
Fern											X
Quack grass			X	X	X	X	X		X	X	X
Western yarrow										X	

In Field "C", there are 4 transects. Transect 1 consists of three areas; Area 1 is a 400 foot upland, Area 2 is a 20 foot riparian and Area 3 is a 100 foot upland. Transect 2 consists of three areas; Area 1 is a 140 foot upland, Area 2 is a 20 foot riparian and Area 3 is a 150 foot upland. Transect 3 consists of three areas; Area 1 is a 300 foot upland, Area 2 is a 10 foot riparian and Area 3 is a 370 foot upland. Transect 4 consists of two areas; Area 1 is a 200 foot upland and Area 2 is a 15 foot riparian.

All footages are estimates.

SPELLMAN IRRIGATION
CEDAR DRAW UNITS

SPELLMAN FIELD "D"

This field had been swathed prior to the vegetative inventory. The riparian area varies from 10 feet to 25 feet wide. The dominate vegetation consists of 25% Carex spp, 25% Prairie cordgrass, 15% Western wheatgrass, 10% Saltgrass and 15% Foxtail barley. The Upland area in transect 2 and area 5 in transect 3 are above the normal flood plain. All other areas are subject to flooding. The dominant vegetation on the upland areas consists of 45% western wheatgrass, 10% Inland saltgrass, 10% Poa spp, and 5% Foxtail barley. The vegetation in Area 1 – transect 1 is being influenced by run off from a big draw that is coming in from the North. A few old Plains cottonwood trees occur on this site. Primary shrub species are silver sagebrush and Greasewood.

The following is a chart of percentages of the species represented in each area of each transect. The "X" indicates the presence of the species in the transect. The "XX" indicates the presence of the species at a level between 1 and 3% of the composition. Together the "X" and "XX" make up the balance of the composition.

	TRANSECT 1				TRANSECT 2				TRANSECT 3					
	Area 1	Area 2	Area 3	Area 4	Area 1	Area 2	Area 3	Area 4	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6
Western wheatgrass	30	10	30	50	30	40	20	50	65	15	35	X	45	60
Inland salt grass	20	10	30	10	X	10	X	X		X	10	10	5	
Foxtail barley	20	15	XX	5	X	20	20	5	5	10	5	30		X
Poa spp.	15	5	15	5	5	15		10	5	5	15	10	5	10
Canada thistle	X													X
Carex spp.	5	20				5	25	X		35		35		15
Japanese brome	XX		XX	5	5			10	XX		15		5	X
Downy brome	XX		XX	X	XX			X	XX		X		XX	X
Greasewood		X	X	10	10	X								
Curlycup gumweed	X		5	5	XX	X	X	10	5	X	10		10	X

SPELLMAN FIELD "D"
Page 2

	TRANSECT 1				TRANSECT 2				TRANSECT 3					
	Area 1	Area 2	Area 3	Area 4	Area 1	Area 2	Area 3	Area 4	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6
Prickly lettuce	X				X						X		X	
Western yarrow	X			X		X								X
Prairie cordgrass	XX	35					20			20		5		
Field bindweed	X		X		X								X	X
Kochia		X	5	X	15			5	5		5	X	15	
Marshelder			XX	X	X			X	XX		X		X	X
Western salsify				X					X				X	X
Flixweed				X										
Pennycress				X							X		X	X
Yellow sweetclover				X										X
Silver sagebrush				X	5									
Quack grass					10									X
Rocky Mtn. Beeplant					X									X
Alfalfa						5				5		5		5
Slender wheatgrass							5							
Bearded wheatgrass						5				5		5		5
Crested wheatgrass									5		X			X
Leafy spurge													X	X
Green needle grass														10
Orchard grass														X
Scurfpea														X

Transect 1 consists of 4 areas. Area 1 is an 80 foot upland that is being influenced by an incoming draw. Area 2 is a 20 foot riparian. Area 3 is a 70 foot upland and Area 4 is a 60 foot upper bench. Transect 2 consists of 4 areas. Area 1 is 150 foot bench that is out of the normal flood zone. Area 2 is a 90 foot lower bench. Area 3 is a 25 foot riparian and Area 4 is a 70 foot upland. Transect consists of 6 areas. Area 1 is a 50 foot upper bench. Area 2 is a 25 foot riparian. Area 3 is a 100 foot lower bench. Area 4 is a second riparian 10 feet in width. Area 5 is 130 foot upper bench that is out of the normal flood zone and Area 6 is a 130 foot lower bench. All footages are estimates.

VEGETATIVE LIST

COMMON NAME	SCIENTIFIC NAME
SHRUBS	
Native Perennial	
Silver sagebrush	Artemisia cana
Sand sagebrush	Artemisia filifolia
Fringed sagebrush	Artemisia frigida
Big sagebrush	Artemisia tridentate
Western snowberry	Symphoricarpos occidentalis
Greasewood	Sarcobatus vermiculatus
TREES	
Native	
Plains cottonwood	Populus angustifolia
Introduced	
Russian olive	Elaeagnus angustifolia
FORBS	
Native Perennials	
Western yarrow	Achillea lanulosa
Plains pricklypear	Opuntia polyacantha
Two Grooved milkvetch	Astragalus bisulcatus
Wild licorice	Glycyrrhiza lepidota
Native Annuals	
Common sunflower	Helianthus annuus
Marshelder	Iva xanthifolia
Western sticktight	Loppula redowski
Smallseed falseflex	Camelina microcarpa
Flixweed	Descurainia sophia
Rocky Mountain beeplant	Clome serrulata
Woolly plantain	Plantago patagonica
Introduced Annuals	
Redroot pigweed	Amaranthus retroflexus
Common ragweed	Ambrosia artemisiifolia

Yellow alyssum	Alyssum alyssoides
Clasping pepperweed	Lepidium perfoliatum
Field pennycress	Thlaspi arvense
Kochia	Kochia scoparia
Common lambsquarter	Chenopodium album
Russian thistle	Salsola iberica
Common mallow	Malva neglecta

Introduced Perennial

Canada thistle	Cirsium arvense
Dandelion	Taraxacum spp
Field bindweed	Convolvulus aryensis
Leafy spurge	Euphorbia esula
Curly dock	Rumex crispus

Native Biennial

Common sagewort	Artemisia campestris
Plumeless thistle	Carduas acanthoides
Curlycup gumweed	Grindelia squarrosa

Introduced Biennial

Prickly lettuce	Lactuca serriola
Scotch thistle	Onopordum acanthium
Western Salsify	Troqopogon dubius
Yellow sweetclover	Melilotus officinalis

NATIVE GRASSES
Perennial

Western wheat	Pascopyrum smithie (Agropyron smithie)
Foxtail barley	Hordeum jubatum
Prarie cordgrass	Spartina pectinata
Salt grass	Distichtis stricta
Green needle grass	Stipa viridula
Needle and thread	Stipa comata
June grass	Koleria pyramidaya
Giant wildrye	Elymus cinerus (Russian wildrye – Elymus janceus)
Slender wheatgrass	Agropyrom trachycaulum (Elymus trachcaulus)
Bearded wheatgrass	Agropyrom subsecundum

INTRODUCED GRASSES

Perennial

Crested wheatgrass	Agropyron cristatum
Intermediate wheatgrass	Agropyron intermedian (Elytrigia intermedia)
Smooth brome	Bromus inermis
Quack grass (common)	Agropyron repens (Elytrigia repens)
Orchard grass (common)	Dactylis glomerata
Timothy	Phleum pratensis

Annuals

Japenese brome	Bromus japanicus
Downy brome	Bromus tectorum (Bromus secalinus)
Common rye	Secale cereale

Appendix B

MEMORANDUM

WWC ENGINEERING
1849 Terra Avenue Sheridan, Wyoming 82801
PHONE: (307) 672-0761 FAX: (307) 674-4265 E-MAIL infoshr@wwcengineering.com

TO: **Peggy Carter, Williams Production RMT Co.**

FROM: **Lindy Johnson, Project Engineer**

DATE: **May 19, 2005**

RE: **Mixing Analysis for Water Quality Reaching Bob Spellman's Irrigated Land**

Mixing calculations were performed to provide an estimate of the water quality resulting from significant storm events that overflow reservoirs used for containment of CBNG discharge water. The analysis used the runoff volumes calculated for various storm events to determine the amount of CBNG water displaced from reservoirs. The focus of this analysis is the drainage area above each reservoir and the water quality of mixed water discharging from each reservoir at the point of irrigation along Middle Prong Wild Horse Creek.

The mixing analysis assumes that the water stored in the reservoirs prior to the storm event is 100 percent CBNG water and that during a storm event the amount of runoff developing above each reservoir will be thoroughly mixed with the CBNG water such that the water spilling from the reservoir will be a uniform mixture of natural runoff and CBNG water. These assumptions are conservative. It is likely that the water stored in the reservoirs will not be 100 percent CBNG water, but will always contain some natural runoff from the drainages upstream of the reservoirs. Also, during a storm event, the runoff is not likely to fully mix with the water stored in the reservoir, but the less dense runoff will rather tend to pass across the top of the reservoir. This would cause more pure runoff to spill and leave more of the CBNG water in storage.

The mixing analysis was performed for storm events with return intervals ranging from 2 years to 100 years. Except during significant runoff events such as these, the CBNG water will evaporate and infiltrate in the containment reservoirs without discharging to Middle Prong Wild Horse Creek.

The mixing calculations were performed as follows: first, runoff volumes at the reservoirs were used to calculate the volume of water (runoff and CBNG water) that will spill from each reservoir. Second, the proportion of CBNG water in the reservoir discharges was calculated according to the relative amounts of CBNG water in storage and runoff entering the reservoirs. Next, the percentage of CBNG water in the runoff reaching the point of irrigation was determined using the volume of CBNG water displaced from the reservoirs and the overall runoff volume for the drainage area upstream of the point of irrigation (subtracting runoff trapped in the reservoirs after mixing). Finally, the quality of the water reaching point of irrigation was estimated from the percent of CBNG water and representative samples of CBNG water and natural runoff.

The natural runoff water quality in the small drainages above the reservoirs was estimated from 18 reservoir water quality analyses available from HUC 10090202 (WRDS 2004). All of the samples were collected in 1974-1976 prior to local CBNG development and represent the relatively high quality of runoff water that accrues in ephemeral and intermittent streams in tributaries of the Powder River. A copy of the water sample results has been included. By including samples with relatively high salinity, which is likely attributed to alluvial discharges and evaporation, a conservatively high estimate of natural runoff salinity was obtained. The mixing calculations are included in this submittal and summarized in Table 1.

Table 1. Mixing Analysis Results.

	CBNG Water	Natural Runoff	Storm Recurrence Interval					
			2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
Percent CBNG Water (%)	100	0	3.3	2.4	2.0	1.6	1.5	1.3
Specific Conductance (µmhos/cm)	2,084.0	1,150.0	1,181.0	1,173.0	1,169.0	1,165.0	1,164.0	1,162.0
Sodium (mg/L)	495.0	56.8	71.2	67.5	65.7	63.9	63.4	62.6
Calcium (mg/L)	25.0	394.3	382.1	385.3	386.8	388.3	388.8	389.4
Magnesium (mg/L)	14.0	102.4	99.5	100.2	100.6	101.0	101.1	101.2
SAR	19.9	0.7	0.8	0.8	0.8	0.7	0.7	0.7

The results of the mixing analysis show that for all of the storm events, the CBNG water will be sufficiently diluted such that the specific conductance of the resultant water mixture is below 2,000 µmhos/cm and the SAR is less than 6.

cc: Brian Heath, Greystone Cheyenne
K:\Williams\05029\01-WMP\MIXING\mixing.wpd

MIXING CALCULATIONS

Project: Cedar Draw Unit 1

Drainage: Upper Middle Prong Wild Horse Creek (Drainage upstream of irrigation)

Storm: 2-yr, 24-hr

CBNG Water and Natural Runoff Volume Analysis

Reservoir Name	Estimated Reservoir Capacity (ac-ft)	Excess Capacity[1] (ac-ft)	CBNG Water Volume[2] (ac-ft)	Natural Runoff Volume[3] and Direct Precip[4] (ac-ft)	Total Volume[5] (ac-ft)	Net Water Spilled (ac-ft)	Ratio of CBNG Water to Total Volume[6]	CBNG Water Leaving Reservoir after Mixing[7] (ac-ft)	Natural Runoff Captured[8] (ac-ft)
43-31	10.50	0.00	10.50	1.90	12.40	1.90	0.85	1.61	1.61
43-32	18.92	0.00	18.92	0.67	19.59	0.67	0.97	0.65	0.65
31-6	3.09	0.00	3.09	0.59	3.68	0.59	0.84	0.49	0.49
32-6	146.00	21.00	125.00	3.49	128.49	0.00	0.97	0.00	3.49
41-8	9.20	0.00	9.20	1.10	10.30	1.10	0.89	0.98	0.98
22-17	7.80	0.00	7.80	1.00	8.80	1.00	0.89	0.88	0.88
North	7.30	0.00	7.30	0.54	7.84	0.54	0.93	0.50	0.50
42-16-5375	17.55	0.00	17.55	1.19	18.74	1.19	0.94	1.11	1.11
Backdoor	8.00	0.00	8.00	0.35	8.35	0.35	0.96	0.34	0.34
Sweet	1.70	0.00	1.70	0.19	1.89	0.19	0.90	0.17	0.17
Snake Charmer	2.00	0.00	2.00	2.40	4.40	2.40	0.45	1.09	1.09
24-15-5375	1.24	0.00	1.24	0.50	1.74	0.50	0.71	0.36	0.36
32-15-5375	5.20	0.00	5.20	3.47	8.67	3.47	0.60	2.08	2.08
11-28	2.00	0.00	2.00	0.54	2.54	0.54	0.79	0.42	0.42
12-34	1.70	0.00	1.70	0.69	2.39	0.69	0.71	0.49	0.49
Lake	3.40	0.00	3.40	0.92	4.32	0.92	0.79	0.72	0.72
41-33A	0.40	0.00	0.40	1.39	1.79	1.39	0.22	0.31	0.31
41-33B	1.50	0.00	1.50	0.29	1.79	0.29	0.84	0.24	0.24
33-21	3.50	0.00	3.50	0.16	3.66	0.16	0.96	0.15	0.15
33-18	9.80	0.00	9.80	0.61	10.41	0.61	0.94	0.57	0.57
32-18	4.50	0.00	4.50	1.36	5.86	1.36	0.77	1.05	1.05
22-18	0.40	0.00	0.40	0.40	0.80	0.40	0.50	0.20	0.20
14-7	5.56	0.00	5.56	3.21	8.77	3.21	0.63	2.04	2.04
			Total	26.94		23.46		**16.46**	**19.95**

Adjusted precipitation for selected storm [9]	1.5	in
Drainage runoff volume [3]	503.0	ac-ft
Drainage runoff volume less runnoff captured	483.1	ac-ft
Percentage CBNG water reaching the mouth of the drainage	3.30	%

Water Quality Analysis

	Water	Runoff[10]	Mixed
Specific Conductance (µmhos/cm)	2,084	1,150	1,181
Sodium (mg/L)	495	56.8	71.2
Calcium (mg/L)	25	394.3	382.1
Magnesium (mg/L)	14	102.4	99.5
SAR	19.9	0.7	0.8

[1] Excess capacity below the invert of the spillway where the waterline of the reservoir will be maintained to ensure freeboard for runoff.

[2] Reservoirs are assumed to contain 100% CBNG water up to the HWL less the excess freeboard when the storm begins.

[3] Calculated using triangular hydrograph method with WWC's TRIHYDRO computer program or with the SCS curve number loss method.

[4] Runoff volume plus the volume of direct precipitation that accrues to the high water line of the reservoir.

[5] CBNG water volume plus the runoff volume and direct precipitation.

[6] CBNG water divided by the total volume.

[7] CBNG water volume ratio multiplied by the difference of the total volume and the reservoir capacity (if positive).

[8] Runoff volume + direct precipitation - (net spill - CBNG water spilled).

[9] Derived from Volume II of the NOAA Precipitation Frequency Atlas of the Western United States.

[10] Median values from 18 samples collated from HUC 10090202 reservoirs.

MIXING CALCULATIONS

Project: Cedar Draw Unit 1

Drainage: Upper Middle Prong Wild Horse Creek (Drainage upstream of irrigation)

Storm: 5-yr, 24-hr

CBNG Water and Natural Runoff Volume Analysis

Reservoir Name	Estimated Reservoir Capacity (ac-ft)	Excess Capacity[1] (ac-ft)	CBNG Water Volume[2] (ac-ft)	Natural Runoff Volume[3] and Direct Precip[4] (ac-ft)	Total Volume[5] (ac-ft)	Net Water Spilled (ac-ft)	Ratio of CBNG Water to Total Volume[6]	CBNG Water Leaving Reservoir after Mixing[7] (ac-ft)	Natural Runoff Captured[8] (ac-ft)
43-31	10.50	0.00	10.50	4.25	14.75	4.25	0.71	3.03	3.03
43-32	18.92	0.00	18.92	0.93	19.85	0.93	0.95	0.89	0.89
31-6	3.09	0.00	3.09	1.24	4.33	1.24	0.71	0.89	0.89
32-6	146.00	21.00	125.00	6.34	131.34	0.00	0.95	0.00	6.34
41-8	9.20	0.00	9.20	2.40	11.60	2.40	0.79	1.90	1.90
22-17	7.80	0.00	7.80	2.02	9.82	2.02	0.79	1.61	1.61
North	7.30	0.00	7.30	1.10	8.40	1.10	0.87	0.96	0.96
42-16-5375	17.55	0.00	17.55	2.59	20.14	2.59	0.87	2.26	2.26
Backdoor	8.00	0.00	8.00	0.61	8.61	0.61	0.93	0.57	0.57
Sweet	1.70	0.00	1.70	0.41	2.11	0.41	0.80	0.33	0.33
Snake Charmer	2.00	0.00	2.00	5.64	7.64	5.64	0.26	1.48	1.48
24-15-5375	1.24	0.00	1.24	1.13	2.37	1.13	0.52	0.59	0.59
32-15-5375	5.20	0.00	5.20	8.08	13.28	8.08	0.39	3.16	3.16
11-28	2.00	0.00	2.00	1.18	3.18	1.18	0.63	0.74	0.74
12-34	1.70	0.00	1.70	1.54	3.24	1.54	0.52	0.81	0.81
Lake	3.40	0.00	3.40	2.08	5.48	2.08	0.62	1.29	1.29
41-33A	0.40	0.00	0.40	3.26	3.66	3.26	0.11	0.36	0.36
41-33B	1.50	0.00	1.50	0.62	2.12	0.62	0.71	0.44	0.44
33-21	3.50	0.00	3.50	0.28	3.78	0.28	0.93	0.26	0.26
33-18	9.80	0.00	9.80	1.19	10.99	1.19	0.89	1.06	1.06
32-18	4.50	0.00	4.50	3.15	7.65	3.15	0.59	1.85	1.85
22-18	0.40	0.00	0.40	0.93	1.33	0.93	0.30	0.28	0.28
14-7	5.56	0.00	5.56	7.42	12.98	7.42	0.43	3.18	3.18
			Total	58.40		52.06		27.92	34.26

Adjusted precipitation for selected storm [9]	1.9	in
Drainage runoff volume [3]	1,150.0	ac-ft
Drainage runoff volume less runnoff captured	1,115.7	ac-ft
Percentage CBNG water reaching the mouth of the drainage	2.44	%

Water Quality Analysis

	Water	Runoff[10]	Mixed
Specific Conductance (µmhos/cm)	2,084	1,150	1,173
Sodium (mg/L)	495	56.8	67.5
Calcium (mg/L)	25	394.3	385.3
Magnesium (mg/L)	14	102.4	100.2
SAR	19.9	0.7	0.8

[1] Excess capacity below the invert of the spillway where the waterline of the reservoir will be maintained to ensure freeboard for runoff.

[2] Reservoirs are assumed to contain 100% CBNG water up to the HWL less the excess freeboard when the storm begins.

[3] Calculated using triangular hydrograph method with WWC's TRIHYDRO computer program or with the SCS curve number loss method.

[4] Runoff volume plus the volume of direct precipitation that accrues to the high water line of the reservoir.

[5] CBNG water volume plus the runoff volume and direct precipitation.

[6] CBNG water divided by the total volume.

[7] CBNG water volume ratio multiplied by the difference of the total volume and the reservoir capacity (if positive).

[8] Runoff volume + direct precipitation - (net spill - CBNG water spilled).

[9] Derived from Volume II of the NOAA Precipitation Frequency Atlas of the Western United States.

[10] Median values from 18 samples collated from HUC 10090202 reservoirs.

MIXING CALCULATIONS

Project: Cedar Draw Unit 1

Drainage: Upper Middle Prong Wild Horse Creek (Drainage upstream of irrigation)

Storm: 10-yr, 24-hr

CBNG Water and Natural Runoff Volume Analysis

Reservoir Name	Estimated Reservoir Capacity (ac-ft)	Excess Capacity[1] (ac-ft)	CBNG Water Volume[2] (ac-ft)	Natural Runoff Volume[3] and Direct Precip[4] (ac-ft)	Total Volume[5] (ac-ft)	Net Water Spilled (ac-ft)	Ratio of CBNG Water to Total Volume[6]	CBNG Water Leaving Reservoir after Mixing[7] (ac-ft)	Natural Runoff Captured[8] (ac-ft)
43-31	10.50	0.00	10.50	6.67	17.17	6.67	0.61	4.08	4.08
43-32	18.92	0.00	18.92	1.20	20.12	1.20	0.94	1.13	1.13
31-6	3.09	0.00	3.09	1.92	5.01	1.92	0.62	1.18	1.18
32-6	146.00	21.00	125.00	9.26	134.26	0.00	0.93	0.00	9.26
41-8	9.20	0.00	9.20	3.74	12.94	3.74	0.71	2.66	2.66
22-17	7.80	0.00	7.80	3.07	10.87	3.07	0.72	2.20	2.20
North	7.30	0.00	7.30	1.69	8.99	1.69	0.81	1.37	1.37
42-16-5375	17.55	0.00	17.55	4.03	21.58	4.03	0.81	3.28	3.28
Backdoor	8.00	0.00	8.00	0.88	8.88	0.88	0.90	0.79	0.79
Sweet	1.70	0.00	1.70	0.64	2.34	0.64	0.73	0.46	0.46
Snake Charmer	2.00	0.00	2.00	8.98	10.98	8.98	0.18	1.64	1.64
24-15-5375	1.24	0.00	1.24	1.78	3.02	1.78	0.41	0.73	0.73
32-15-5375	5.20	0.00	5.20	12.83	18.03	12.83	0.29	3.70	3.70
11-28	2.00	0.00	2.00	1.84	3.84	1.84	0.52	0.96	0.96
12-34	1.70	0.00	1.70	2.42	4.12	2.42	0.41	1.00	1.00
Lake	3.40	0.00	3.40	3.28	6.68	3.28	0.51	1.67	1.67
41-33A	0.40	0.00	0.40	2.20	2.60	2.20	0.15	0.34	0.34
41-33B	1.50	0.00	1.50	0.96	2.46	0.96	0.61	0.58	0.58
33-21	3.50	0.00	3.50	0.41	3.91	0.41	0.90	0.37	0.37
33-18	9.80	0.00	9.80	1.79	11.59	1.79	0.85	1.51	1.51
32-18	4.50	0.00	4.50	4.99	9.49	4.99	0.47	2.37	2.37
22-18	0.40	0.00	0.40	1.47	1.87	1.47	0.21	0.31	0.31
14-7	5.56	0.00	5.56	11.76	17.32	11.76	0.32	3.77	3.77
			Total	87.77		78.51		36.10	45.36

Adjusted precipitation for selected storm [9]	2.3	in
Drainage runoff volume [3]	1,790.0	ac-ft
Drainage runoff volume less runnoff captured	1,744.6	ac-ft
Percentage CBNG water reaching the mouth of the drainage	2.03	%

Water Quality Analysis

	Water	Runoff[10]	Mixed
Specific Conductance (μmhos/cm)	2,084	1,150	1,169
Sodium (mg/L)	495	56.8	65.7
Calcium (mg/L)	25	394.3	386.8
Magnesium (mg/L)	14	102.4	100.6
SAR	19.9	0.7	0.8

[1] Excess capacity below the invert of the spillway where the waterline of the reservoir will be maintained to ensure freeboard for runoff.

[2] Reservoirs are assumed to contain 100% CBNG water up to the HWL less the excess freeboard when the storm begins.

[3] Calculated using triangular hydrograph method with WWC's TRIHYDRO computer program or with the SCS curve number loss method.

[4] Runoff volume plus the volume of direct precipitation that accrues to the high water line of the reservoir.

[5] CBNG water volume plus the runoff volume and direct precipitation.

[6] CBNG water divided by the total volume.

[7] CBNG water volume ratio multiplied by the difference of the total volume and the reservoir capacity (if positive).

[8] Runoff volume + direct precipitation - (net spill - CBNG water spilled).

[9] Derived from Volume II of the NOAA Precipitation Frequency Atlas of the Western United States.

[10] Median values from 18 samples collated from HUC 10090202 reservoirs.

MIXING CALCULATIONS

Project: Cedar Draw Unit 1

Drainage: Upper Middle Prong Wild Horse Creek (Drainage upstream of irrigation)

Storm: 25-yr, 24-hr

CBNG Water and Natural Runoff Volume Analysis

Reservoir Name	Estimated Reservoir Capacity (ac-ft)	Excess Capacity[1] (ac-ft)	CBNG Water Volume[2] (ac-ft)	Natural Runoff Volume[3] and Direct Precip[4] (ac-ft)	Total Volume[5] (ac-ft)	Net Water Spilled (ac-ft)	Ratio of CBNG Water to Total Volume[6]	CBNG Water Leaving Reservoir after Mixing[7] (ac-ft)	Natural Runoff Captured[8] (ac-ft)
43-31	10.50	0.00	10.50	10.19	20.69	10.19	0.51	5.17	5.17
43-32	18.92	0.00	18.92	1.58	20.50	1.58	0.92	1.46	1.46
31-6	3.09	0.00	3.09	2.91	6.00	2.91	0.52	1.50	1.50
32-6	146.00	21.00	125.00	13.55	138.55	0.00	0.90	0.00	13.55
41-8	9.20	0.00	9.20	5.68	14.88	5.68	0.62	3.51	3.51
22-17	7.80	0.00	7.80	4.60	12.40	4.60	0.63	2.90	2.90
North	7.80	0.00	7.80	4.60	12.40	4.60	0.63	2.90	2.90
42-16-5375	7.30	0.00	7.30	2.52	9.82	2.52	0.74	1.87	1.87
Backdoor	17.55	0.00	17.55	6.14	23.69	6.14	0.74	4.55	4.55
Sweet	8.00	0.00	8.00	1.28	9.28	1.28	0.86	1.10	1.10
Snake Charme	1.70	0.00	1.70	0.97	2.67	0.97	0.64	0.62	0.62
24-15-5375	2.00	0.00	2.00	13.83	15.83	13.83	0.13	1.75	1.75
32-15-5375	1.24	0.00	1.24	2.73	3.97	2.73	0.31	0.85	0.85
11-28	5.20	0.00	5.20	19.74	24.94	19.74	0.21	4.12	4.12
12-34	2.00	0.00	2.00	2.81	4.81	2.81	0.42	1.17	1.17
Lake	1.70	0.00	1.70	3.69	5.39	3.69	0.32	1.16	1.16
41-33A	3.40	0.00	3.40	5.02	8.42	5.02	0.40	2.03	2.03
41-33B	0.40	0.00	0.40	8.01	8.41	8.01	0.05	0.38	0.38
33-21	1.50	0.00	1.50	1.45	2.95	1.45	0.51	0.74	0.74
33-18	3.50	0.00	3.50	0.59	4.09	0.59	0.86	0.50	0.50
32-18	9.80	0.00	9.80	2.66	12.46	2.66	0.79	2.09	2.09
22-18	4.50	0.00	4.50	7.67	12.17	7.67	0.37	2.84	2.84
14-7	0.40	0.00	0.40	2.26	2.66	2.26	0.15	0.34	0.34
			Total	124.49		110.94		43.54	57.09

Adjusted precipitation for selected storm [9]	2.9	in
Drainage runoff volume [3]	2,705.0	ac-ft
Drainage runoff volume less runnoff captured	2,647.9	ac-ft
Percentage CBNG water reaching the mouth of the drainage	1.62	%

Water Quality Analysis

	Water	Runoff[10]	Mixed
Specific Conductance (μmhos/cm)	2,084	1,150	1,165
Sodium (mg/L)	495	56.8	63.9
Calcium (mg/L)	25	394.3	388.3
Magnesium (mg/L)	14	102.4	101.0
SAR	19.9	0.7	0.7

[1] Excess capacity below the invert of the spillway where the waterline of the reservoir will be maintained to ensure freeboard for runoff.

[2] Reservoirs are assumed to contain 100% CBNG water up to the HWL less the excess freeboard when the storm begins.

[3] Calculated using triangular hydrograph method with WWC's TRIHYDRO computer program or with the SCS curve number loss method.

[4] Runoff volume plus the volume of direct precipitation that accrues to the high water line of the reservoir.

[5] CBNG water volume plus the runoff volume and direct precipitation.

[6] CBNG water divided by the total volume.

[7] CBNG water volume ratio multiplied by the difference of the total volume and the reservoir capacity (if positive).

[8] Runoff volume + direct precipitation - (net spill - CBNG water spilled).

[9] Derived from Volume II of the NOAA Precipitation Frequency Atlas of the Western United States.

[10] Median values from 18 samples collated from HUC 10090202 reservoirs.

MIXING CALCULATIONS

Project: Cedar Draw Unit 1

Drainage: Upper Middle Prong Wild Horse Creek (Drainage upstream of irrigation)

Storm: 50-yr, 24-hr

CBNG Water and Natural Runoff Volume Analysis

Reservoir Name	Estimated Reservoir Capacity (ac-ft)	Excess Capacity[1] (ac-ft)	CBNG Water Volume[2] (ac-ft)	Natural Runoff Volume[3] and Direct Precip[4] (ac-ft)	Total Volume[5] (ac-ft)	Net Water Spilled (ac-ft)	Ratio of CBNG Water to Total Volume[6]	CBNG Water Leaving Reservoir after Mixing[7] (ac-ft)	Natural Runoff Captured[8] (ac-ft)
43-31	10.50	0.00	10.50	12.44	22.94	12.44	0.46	5.69	5.69
43-32	18.92	0.00	18.92	1.80	20.72	1.80	0.91	1.64	1.64
31-6	3.09	0.00	3.09	3.53	6.62	3.53	0.47	1.65	1.65
32-6	146.00	21.00	125.00	16.20	141.20	0.00	0.89	0.00	16.20
41-8	9.20	0.00	9.20	6.92	16.12	6.92	0.57	3.95	3.95
22-17	7.80	0.00	7.80	5.57	13.37	5.57	0.58	3.25	3.25
North	7.30	0.00	7.30	3.06	10.36	3.06	0.70	2.16	2.16
42-16-5375	17.55	0.00	17.55	7.48	25.03	7.48	0.70	5.25	5.25
Backdoor	8.00	0.00	8.00	1.52	9.52	1.52	0.84	1.27	1.27
Sweet	1.70	0.00	1.70	1.18	2.88	1.18	0.59	0.70	0.70
nake Charme	2.00	0.00	2.00	16.94	18.94	16.94	0.11	1.79	1.79
24-15-5375	1.24	0.00	1.24	3.34	4.58	3.34	0.27	0.90	0.90
32-15-5375	5.20	0.00	5.20	24.17	29.37	24.17	0.18	4.28	4.28
11-28	2.00	0.00	2.00	3.42	5.42	3.42	0.37	1.26	1.26
12-34	1.70	0.00	1.70	4.51	6.21	4.51	0.27	1.23	1.23
Lake	3.40	0.00	3.40	6.13	9.53	6.13	0.36	2.19	2.19
41-33A	0.40	0.00	0.40	9.81	10.21	9.81	0.04	0.38	0.38
41-33B	1.50	0.00	1.50	1.76	3.26	1.76	0.46	0.81	0.81
33-21	3.50	0.00	3.50	0.71	4.21	0.71	0.83	0.59	0.59
33-18	9.80	0.00	9.80	3.21	13.01	3.21	0.75	2.42	2.42
32-18	4.50	0.00	4.50	9.38	13.88	9.38	0.32	3.04	3.04
22-18	0.40	0.00	0.40	2.77	3.17	2.77	0.13	0.35	0.35
14-7	5.56	0.00	5.56	22.09	27.65	22.09	0.20	4.44	4.44
			Total	167.93		151.73		**49.25**	**65.44**

Adjusted precipitation for selected storm [9]	3.2	in
Drainage runoff volume [3]	3,302.0	ac-ft
Drainage runoff volume less runnoff captured	3,236.6	ac-ft
Percentage CBNG water reaching the mouth of the drainage	1.50	%

Water Quality Analysis

	Water	Runoff[10]	Mixed
Specific Conductance (µmhos/cm)	2,084	1,150	1,164
Sodium (mg/L)	495	56.8	63.4
Calcium (mg/L)	25	394.3	388.8
Magnesium (mg/L)	14	102.4	101.1
SAR	19.9	0.7	0.7

[1] Excess capacity below the invert of the spillway where the waterline of the reservoir will be maintained to ensure freeboard for runoff.

[2] Reservoirs are assumed to contain 100% CBNG water up to the HWL less the excess freeboard when the storm begins.

[3] Calculated using triangular hydrograph method with WWC's TRIHYDRO computer program or with the SCS curve number loss method.

[4] Runoff volume plus the volume of direct precipitation that accrues to the high water line of the reservoir.

[5] CBNG water volume plus the runoff volume and direct precipitation.

[6] CBNG water divided by the total volume.

[7] CBNG water volume ratio multiplied by the difference of the total volume and the reservoir capacity (if positive).

[8] Runoff volume + direct precipitation - (net spill - CBNG water spilled).

[9] Derived from Volume II of the NOAA Precipitation Frequency Atlas of the Western United States.

[10] Median values from 18 samples collated from HUC 10090202 reservoirs.

MIXING CALCULATIONS

Project: **Cedar Draw Unit 1**
Drainage: **Upper Middle Prong Wild Horse Creek (Drainage upstream of irrigation)**
Storm: **100-yr, 24-hr**

CBNG Water and Natural Runoff Volume Analysis

Reservoir Name	Estimated Reservoir Capacity (ac-ft)	Excess Capacity[1] (ac-ft)	CBNG Water Volume[2] (ac-ft)	Natural Runoff Volume[3] and Direct Precip[4] (ac-ft)	Total Volume[5] (ac-ft)	Net Water Spilled (ac-ft)	Ratio of CBNG Water to Total Volume[6]	CBNG Water Leaving Reservoir after Mixing[7] (ac-ft)	Natural Runoff Captured[8] (ac-ft)
43-31	10.50	0.00	10.50	15.81	26.31	15.81	0.40	6.31	6.31
43-32	18.92	0.00	18.92	2.11	21.03	2.11	0.90	1.90	1.90
31-6	3.09	0.00	3.09	4.47	7.56	4.47	0.41	1.83	1.83
32-6	146.00	21.00	125.00	20.12	145.12	0.00	0.86	0.00	20.12
41-8	9.20	0.00	9.20	8.77	17.97	8.77	0.51	4.49	4.49
22-17	7.80	0.00	7.80	7.00	14.80	7.00	0.53	3.69	3.69
North	7.30	0.00	7.30	3.86	11.16	3.86	0.65	2.52	2.52
42-16-5375	17.55	0.00	17.55	9.49	27.04	9.49	0.65	6.16	6.16
Backdoor	8.00	0.00	8.00	1.87	9.87	1.87	0.81	1.52	1.52
Sweet	1.70	0.00	1.70	1.49	3.19	1.49	0.53	0.79	0.79
Snake Charmer	2.00	0.00	2.00	21.62	23.62	21.62	0.08	1.83	1.83
24-15-5375	1.24	0.00	1.24	4.25	5.49	4.25	0.23	0.96	0.96
32-15-5375	5.20	0.00	5.20	30.83	36.03	30.83	0.14	4.45	4.45
11-28	2.00	0.00	2.00	4.34	6.34	4.34	0.32	1.37	1.37
12-34	1.70	0.00	1.70	5.74	7.44	5.74	0.23	1.31	1.31
Lake	3.40	0.00	3.40	7.81	11.21	7.81	0.30	2.37	2.37
41-33A	0.40	0.00	0.40	12.54	12.94	12.54	0.03	0.39	0.39
41-33B	1.50	0.00	1.50	12.16	13.66	12.16	0.11	1.34	1.34
33-21	3.50	0.00	3.50	0.88	4.38	0.88	0.80	0.70	0.70
33-18	9.80	0.00	9.80	4.02	13.82	4.02	0.71	2.85	2.85
32-18	4.50	0.00	4.50	11.96	16.46	11.96	0.27	3.27	3.27
22-18	0.40	0.00	0.40	3.52	3.92	3.52	0.10	0.36	0.36
14-7	5.56	0.00	5.56	28.17	33.73	28.17	0.16	4.64	4.64
			Total	**222.83**		**202.71**		**55.04**	**75.16**

Adjusted precipitation for selected storm[9]	3.6	in
Drainage runoff volume[3]	4,145.0	ac-ft
Drainage runoff volume less runnoff captured	4,069.8	ac-ft
Percentage CBNG water reaching the mouth of the drainage	1.33	%

Water Quality Analysis

	Water	Runoff[10]	Mixed
Specific Conductance (μmhos/cm)	2,084	1,150	1,162
Sodium (mg/L)	495	56.8	62.6
Calcium (mg/L)	25	394.3	389.4
Magnesium (mg/L)	14	102.4	101.2
SAR	19.9	0.7	0.7

[1] Excess capacity below the invert of the spillway where the waterline of the reservoir will be maintained to ensure freeboard for runoff.

[2] Reservoirs are assumed to contain 100% CBNG water up to the HWL less the excess freeboard when the storm begins.

[3] Calculated using triangular hydrograph method with WWC's TRIHYDRO computer program or with the SCS curve number loss method.

[4] Runoff volume plus the volume of direct precipitation that accrues to the high water line of the reservoir.

[5] CBNG water volume plus the runoff volume and direct precipitation.

[6] CBNG water divided by the total volume.

[7] CBNG water volume ratio multiplied by the difference of the total volume and the reservoir capacity (if positive).

[8] Runoff volume + direct precipitation - (net spill - CBNG water spilled).

[9] Derived from Volume II of the NOAA Precipitation Frequency Atlas of the Western United States.

[10] Median values from 18 samples collated from HUC 10090202 reservoirs.

Natural Water Quality in Reservoirs and Ponds in HUC 10090202

WRDS Station ID	Latitude	Longitude	Watershed	Sample Date	EC	Ca	Mg	Na	SAR
200998	44.6683	106.0783	N. Fork Fourmile Creek	5/22/1976	150				
201217	44.1750	106.2755	Indian Creek (Indian Creek Reservoir)	5/31/1976	900	241.3	69.5	56.6	0.8
201219	44.2005	106.2938	Indian Creek (UT)	5/31/1976	600	394.3	102.4	65.9	0.8
201222	44.2750	106.3194	Flying E Creek (UT)	5/31/1976	2,000	483.2	147.0	160.9	1.6
201766	44.1000	106.0622	Beaver Creek (UT)	10/9/1976	1,100	246.3	40.8	56.8	0.9
W04068	44.2819	105.6800	S Bar Creek	4/5/1976	1,200				
W04070	44.2733	105.6927	East Fork Wild Horse Creek (UT)	4/5/1974	1,900				
W04072	44.2847	105.7119	East Fork Wild Horse Creek	4/5/1976	10,000				
W04228	44.2872	105.7883	Kingsbury Creek	4/5/1976	4,700				
W04231	44.2827	105.8352	Kingsbury Creek (UT)	4/5/1976	1,900				
W04247	44.1902	105.7227	Wild Horse Creek (UT)	4/3/1976	3,000	410.5	187.4	26.2	0.3
W04251	44.2222	105.7369	Wild Horse Creek (UT)	4/3/1976	1,200				
W04261	44.2005	105.6922	Wild Horse Creek (UT)	4/4/1976	200				
W04315	44.6711	105.8505	Linn Draw	4/6/1976	350				
W04349	44.3244	105.7063	Hay Creek (UT)	4/7/1976	230				
W04350	44.3194	105.8016	Sand Draw (WHC Tributary)	4/7/1976	3,200				
W04351	44.3327	105.7808	Bekebrede Draw	4/7/1976	470				
W04428	44.7769	105.8902	Playa near Spotted Horse Creek	4/8/1976	200				
			Median Water Quality		**1,150**	**394.3**	**102.4**	**56.8**	**0.7**

UT - Unnamed Tributary
WHC - Wild Horse Creek

Source: Wyoming Water Resources Data System, Powder River Basin IMS Online, available on the Internet May 2004: http://ims.wrds.uwyo.edu

ENERGY LABORATORIES, INC. * 1105 West First Street. * Gillette, WY 82716
Toll Free 866.686.7175 * 307.686.7175 * Fax 307.682.4625 * gillette@energylab.com

LABORATORY ANALYTICAL REPORT **Revised Date:** 02/01/05

Client: Williams Production RMT
Site Name: North_Cedar_Draw_POD
Project: NPDES
Samp FRQ/Type: IR
Client Sample ID: DP_WY0050865_004_TP
Location: SENE_16_53N_75W

Lab ID: G04090176-001
Report Date: 09/23/04
Collection Date: 09/09/04 11:00
DateReceived: 09/10/04
Sampled By: Todd Adams
Matrix: AQUEOUS
Tracking Number: 39658

Analyses	Result	Units	Qualifiers	RL	QCL	Method	Analysis Date / By
MAJOR IONS							
Bicarbonate as HCO3	1450	mg/L		5		A2320 B	09/13/04 14:23 / mli
Chloride	8	mg/L		1		E300.0	09/11/04 13:49 / mli
Fluoride	0.6	mg/L		0.1		E300.0	09/11/04 13:49 / mli
Sulfate	ND	mg/L		1		E300.0	09/11/04 13:49 / mli
Calcium	26	mg/L		1		E200.7	09/14/04 18:22 / rlh
Magnesium	15	mg/L		1		E200.7	09/14/04 18:22 / rlh
Potassium	9	mg/L		1		E200.7	09/14/04 18:22 / rlh
Sodium	474	mg/L		1		E200.7	09/14/04 18:22 / rlh
MAJOR IONS - MILLIEQUIVALENTS							
Calcium, meq	1.29	meq/L		0.05		E200.7	09/14/04 18:22 / rlh
Magnesium, meq	1.20	meq/L		0.08		E200.7	09/14/04 18:22 / rlh
Sodium, meq	20.6	meq/L		0.04		E200.7	09/14/04 18:22 / rlh
NON-METALS							
Alkalinity, Total as CaCO3	1190	mg/L		5		A2320 B	09/13/04 14:23 / mli
Conductivity @ 25 C	2050	umhos/cm		1		A2510 B	09/10/04 11:24 / daa
Sodium Adsorption Ratio (SAR)	18.5	unitless		0.1		Calculation	09/21/04 09:59 / clw
DATA QUALITY							
A/C Balance	-1.59	%				A1030 E	09/21/04 09:58 / clw
Anions	24.1	meq/L		0.01		A1030 E	09/21/04 09:58 / clw
Cations	23.3	meq/L		0.01		A1030 E	09/21/04 09:58 / clw

Report Definitions:
RL - Analyte reporting limit.
QCL - Quality control limit.
MCL - Maximum contaminant level.
ND - Not detected at the reporting limit.

ENERGY LABORATORIES, INC. * 1105 W First St * Gillette, WY 82716
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LABORATORY ANALYTICAL REPORT

Client:	Williams Production RMT		
Site Name:	Cedar_Draw_State	**Report Date:**	03/15/05
Project:	Produced_Water	**Collection Date:**	03/08/05 11:30
Client Sample ID:	PW_41_23_5376G_49_005_47984	**DateReceived:**	03/08/05
Location:	NENE_23_53N_76W	**Sampled By:**	Jake Morrison
Samp FRQ/Type:	OT	**Matrix:**	AQUEOUS
Lab ID:	G05030113-003	**Tracking Number:**	46079

Analyses	Result	Units	Result	Units	Qualifier	Method	Analysis Date / By
FIELD PARAMETERS							
pH, field	7.54	s.u.				FIELD	03/08/05 11:30 / ***
*** Performed by Sampler							
MAJOR IONS							
Bicarbonate as HCO3	1500	mg/L	24.6	meq/L		A2320 B	03/09/05 10:27 / mli
Chloride	13	mg/L	0.36	meq/L		E300.0	03/09/05 13:04 / mli
Sulfate	<1	mg/L	<0.02	meq/L		E300.0	03/09/05 13:04 / mli
Calcium	23	mg/L	1.14	meq/L		E200.7	03/10/05 15:40 / rlh
Magnesium	12	mg/L	1.02	meq/L		E200.7	03/10/05 15:40 / rlh
Sodium	517	mg/L	22.5	meq/L		E200.7	03/10/05 15:40 / rlh
METALS, DISSOLVED							
Cadmium	<0.1	ug/L				E200.8	03/14/05 19:14 / jjw
Copper	11	ug/L				E200.8	03/14/05 19:14 / jjw
Iron	124	ug/L				E200.7	03/10/05 15:40 / rlh
Lead	<2	ug/L				E200.8	03/14/05 19:14 / jjw
Manganese	11	ug/L				E200.7	03/10/05 15:40 / rlh
Mercury	<0.06	ug/L				E200.8	03/14/05 19:14 / jjw
Zinc	<10	ug/L				E200.8	03/14/05 19:14 / jjw
METALS, TOTAL							
Barium	802	ug/L				E200.7	03/11/05 18:25 / rlh
METALS, TOTAL RECOVERABLE							
Aluminum	<50	ug/L				E200.8	03/11/05 21:00 / car
Arsenic	<0.1	ug/L				E200.8	03/11/05 21:00 / car
Beryllium	<0.03	ug/L				E200.8	03/14/05 18:17 / jjw
Selenium	<5	ug/L				E200.8	03/11/05 21:00 / car
NON-METALS							
Alkalinity, Total as CaCO3	1230	mg/L				A2320 B	03/09/05 10:27 / mli
Conductivity @ 25 C	2120	umhos/cm				A2510 B	03/08/05 16:31 / daa
Hardness as CaCO3	110	mg/L				A2340 B	03/15/05 11:42 / clw
Sodium Adsorption Ratio (SAR)	21.7	unitless				Calculation	03/15/05 11:42 / clw
Solids, Total Dissolved TDS @ 180 C	1340	mg/L				A2540 C	03/09/05 11:32 / mli
Total Petroleum Hydrocarbons	<1.0	mg/L				SW1664A	03/10/05 17:15 / ton
RADIOCHEMICAL							
Radium 226	<0.2	pCi/L				E903.0M	03/10/05 14:40 / df

Report Definitions:
RL - Analyte reporting limit.
QCL - Quality control limit.
MCL - Maximum contaminant level.
ND - Not detected at the reporting limit.

Appendix C

ENERGY LABORATORIES

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

LABORATORY ANALYTICAL REPORT

Client: Williams Production RMT
Project: Middle Prong Wild Horse Ck, Section 20
Workorder: H05070131

Report Date: 08/02/05
Date Received: 07/18/05

		Analysis		pH-SatPst	COND	Percent Sat	SAR	Ca-SatPst	Mg-SatPst	Na-SatPst	K-SatPst	Sand	Silt	Clay
		Units		s_u_	mmhos/cm	%	unitless	meq/l	meq/l	meq/l	meq/l	%	%	%
Sample ID	Client Sample ID	Up	Low	Results	Results	Results	Results	Results	Results	Results	Results	Results	Results	Results
H05070131-001	Spell A 0-6	0	6	7.2	5.24	64.0	7.8	26.1	13.6	35.0	1.10	19	50	31
H05070131-002	Spell A 6-12	6	12	8.0	11.1	61.4	22	25.0	28.3	116	0.65	21	47	32
H05070131-003	Spell A 12-24	12	24	8.3	15.5	58.7	29	23.6	44.5	169	0.67	23	46	31
H05070131-004	Spell A 24-36	24	36	8.2	12.5	62.0	23	22.5	36.7	127	0.54	24	46	30
H05070131-005	Spell A 36-48	36	48	8.0	12.7	62.9	24	30.4	39.9	143	0.79	24	44	32
H05070131-006	Spell A 48-60	48	60	7.7	9.55	55.6	17	24.7	26.8	85.4	0.72	33	39	28
H05070131-007	Spell A 60-96	60	96	7.4	8.13	48.3	9.9	22.2	15.9	43.4	0.79	37	37	26
H05070131-008	Spell B 0-6	0	6	7.0	2.68	70.0	1.4	23.1	7.87	5.65	1.40	12	52	36
H05070131-009	Spell B 6-12	6	12	7.5	4.35	51.2	6.6	25.2	11.7	28.5	0.75	22	49	29
H05070131-010	Spell B 12-24	12	24	8.1	10.8	60.1	23	22.7	30.5	117	0.48	14	54	32
H05070131-011	Spell B 24-36	24	36	8.2	13.3	61.2	22	23.1	46.7	130	0.50	16	51	33
H05070131-012	Spell B 36-48	36	48	7.9	8.80	56.8	16	20.3	29.4	78.9	0.53	21	49	30
H05070131-013	Spell B 48-60	48	60	7.8	9.75	58.1	16	23.9	32.6	85.8	0.57	29	39	32
H05070131-014	Spell B 60-96	60	96	7.6	7.20	52.0	12	23.9	26.0	59.1	0.66	36	37	27
H05070131-015	Spell C 0-6	0	6	6.9	3.41	68.8	3.1	25.2	13.3	13.8	1.45	16	46	38
H05070131-016	Spell C 6-12	6	12	7.3	4.11	58.8	5.1	23.9	13.7	22.2	0.64	28	42	30
H05070131-017	Spell C 12-24	12	24	7.7	6.23	56.7	9.9	21.9	20.5	45.5	0.44	24	45	31
H05070131-018	Spell C 24-36	24	36	7.8	9.82	54.3	15	25.0	35.2	82.6	0.63	20	49	31
H05070131-019	Spell C 36-48	36	48	7.8	9.55	60.8	14	25.5	35.1	79.0	0.60	14	50	36
H05070131-020	Spell C 48-60	48	60	7.9	8.63	61.2	14	23.1	37.9	76.2	0.62	18	45	37
H05070131-021	Spell C 60-96	60	96	7.8	7.82	50.1	12	21.9	30.8	60.5	0.54	< 1	48	52
H05070131-022	Spell D 0-6	0	6	7.1	7.81	73.7	11	23.9	31.6	58.6	1.60	7	56	37
H05070131-023	Spell D 6-12	6	12	8.1	14.1	56.9	21	23.5	61.6	139	0.95	22	48	30
H05070131-024	Spell D 12-24	12	24	8.4	20.4	71.9	29	22.8	97.5	226	0.91	10	50	40
H05070131-025	Spell D 24-36	24	36	8.3	16.8	81.1	26	21.8	77.9	185	0.91	19	46	35
H05070131-026	Spell D 36-48	36	48	8.0	13.8	58.6	21	21.3	69.5	143	0.87	24	44	32
H05070131-027	Spell D 48-60	48	60	8.0	15.7	50.5	21	24.8	84.1	153	0.96	28	44	28
H05070131-028	Spell D 60-96	60	96	7.7	11.5	55.6	16	21.0	57.9	98.4	0.96	31	41	28

ENERGY LABORATORIES

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LABORATORY ANALYTICAL REPORT

Client: Williams Production RMT
Project: Middle Prong Wild Horse Ck, Section 20
Workorder: H05070131

Report Date: 08/02/05
Date Received: 07/18/05

		Analysis		Texture	OM-WB	CEC	Lime	Na-Ext	Exch Ca	Exch Mg	Exch K	Exch Na	ESP
		Units		unitless	%	meq/100g	%	meq/100g	meq/100g	meq/100g	meq/100g	meq/100g	%
Sample ID	**Client Sample ID**	**Up**	**Low**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**
H05070131-001	Spell A 0-6	0	6	SiCL	3.89	36.5	4.3	3.71	23.4	4.7	0.6	1.5	4.0
H05070131-002	Spell A 6-12	6	12	CL		33.8	4.8	10.0	1630	6.3	0.4	2.9	8.7
H05070131-003	Spell A 12-24	12	24	CL		29.5	4.7	13.7	1630	6.7	0.4	3.8	13
H05070131-004	Spell A 24-36	24	36	CL		32.9	5.1	11.7	1630	7.3	0.4	3.8	12
H05070131-005	Spell A 36-48	36	48	CL		29.9	4.5	10.0	1630	6.3	0.4	1.0	3.4
H05070131-006	Spell A 48-60	48	60	CL		30.0	4.1	7.03	1630	5.9	0.4	2.3	7.6
H05070131-007	Spell A 60-96	60	96	L		28.9	3.8	3.95	1630	4.7	0.4	1.8	6.4
H05070131-008	Spell B 0-6	0	6	SiCL	4.73	38.6	3.9	1.06	25.2	4.2	1.0	0.7	1.7
H05070131-009	Spell B 6-12	6	12	CL		29.8	4.5	2.44	561	4.2	0.4	1.0	3.3
H05070131-010	Spell B 12-24	12	24	SiCL		34.2	4.9	11.5	1630	6.6	0.4	4.4	13
H05070131-011	Spell B 24-36	24	36	SiCL		33.5	4.8	11.9	1630	8.3	0.3	3.9	12
H05070131-012	Spell B 36-48	36	48	CL		33.5	4.6	8.59	1630	8.3	0.5	4.1	12
H05070131-013	Spell B 48-60	48	60	CL		32.6	4.6	7.69	1630	7.2	0.4	2.7	8.3
H05070131-014	Spell B 60-96	60	96	CL		31.8	4.1	4.99	1630	6.0	0.4	1.9	6.0
H05070131-015	Spell C 0-6	0	6	SiCL	4.44	39.4	2.8	2.09	22.0	5.9	1.0	1.1	2.9
H05070131-016	Spell C 6-12	6	12	CL		32.0	3.6	2.28	23.9	4.9	0.4	1.0	3.0
H05070131-017	Spell C 12-24	12	24	CL		31.2	3.9	4.71	1630	6.1	0.3	2.1	6.8
H05070131-018	Spell C 24-36	24	36	SiCL		32.6	4.3	7.87	1630	7.6	0.4	3.4	10
H05070131-019	Spell C 36-48	36	48	SiCL		32.6	4.2	7.63	1630	7.6	0.5	2.8	8.7
H05070131-020	Spell C 48-60	48	60	SiCL		32.2	4.3	7.64	1630	8.0	0.5	3.0	9.3
H05070131-021	Spell C 60-96	60	96	SiC		28.8	3.7	5.26	1630	6.6	0.3	2.2	7.7
H05070131-022	Spell D 0-6	0	6	SiCL	4.60	39.3	4.2	7.03	24.0	8.1	1.0	2.7	6.9
H05070131-023	Spell D 6-12	6	12	CL		29.5	4.3	12.5	1630	8.2	0.5	4.6	16
H05070131-024	Spell D 12-24	12	24	SiC		34.4	4.5	18.4	1630	8.0	0.4	2.1	6.1
H05070131-025	Spell D 24-36	24	36	SiCL		31.8	4.6	15.5	1630	8.4	0.4	4.2	13
H05070131-026	Spell D 36-48	36	48	CL		30.6	4.2	11.6	1630	8.2	0.4	3.2	11
H05070131-027	Spell D 48-60	48	60	CL		25.0	4.1	11.4	1630	7.6	0.4	3.6	15
H05070131-028	Spell D 60-96	60	96	CL		28.9	4.1	8.24	1630	8.2	0.4	2.8	9.6

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:	7-25-05
Reporting Date:	7-26-05
Receipt Date:	7-21-05
Client Job No.:	H05070131
Project Title:	None Given
DCMSL Project:	ELAB7

Client Sample No.:	**H05070131 001**	**H05070131 008**	**H05070131 015**	**H05070131 022**
Clay Fraction <2μm				
Smectite	44	45	33	39
Illite	26	28	32	30
Kaolinite	30	27	34	31

The results may not equal 100% due to rounding.

An oriented clay mount (<2μm) was prepared for x-ray diffraction and scanned over a range of 3° to 40° 2Θ using CuKα radiation, 35kV, 20mA. The mount was 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

Appendix D

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
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Established Series
CAP
03/2003

BORUFF SERIES

The Boruff series consists of very deep, poorly and somewhat poorly drained soils formed in alluvium on flood plains and low stream terraces. Slope ranges from 0 to 3 percent. The mean annual precipitation is about 14 inches and the mean annual air temperature is about 48 degrees F.,

TAXONOMIC CLASS: Fine, smectitic, calcareous, mesic Vertic Fluvaquents

TYPICAL PEDON: Boruff silty clay - on a west facing slope of 1 percent in rangeland. (Colors are for dry soil unless otherwise noted)

A--0 to 2 inches; olive brown (2.5Y 4/3) silty clay, dark olive brown (2.5Y 3/3) moist; common fine distinct dark yellowish brown (10YR 4/6) redoximorphic concentrations; moderate fine and medium granular structure; slightly hard, friable, moderately sticky and moderately plastic; many very fine roots throughout and common medium throughout; many fine pores; slightly effervescent; slightly alkaline; EC of 3.5; abrupt smooth boundary. (2 to 10 inches thick)

C1--2 to 6 inches; stratified light yellowish brown (2.5Y 6/3) silty clay, light olive brown (2.5Y 5/3) and olive brown (2.5Y 4/3) moist; common fine distinct gray (N 6/0) redoximorphic depletions and common fine prominent dark yellowish brown (10YR 4/6) redoximorphic concentrations; moderate coarse prismatic structure parting to moderate medium subangular blocky; hard, firm, very sticky and very plastic; common very fine roots throughout and common medium throughout; many fine pores; few distinct discontinuous dark brown (10YR 3/3) organic coats in root channels and/or pores; common fine irregular white (10YR 8/1) nests of gypsum throughout; slightly effervescent; moderately alkaline; EC of 5; abrupt wavy boundary.

C2--6 to 46 inches; grayish brown (2.5Y 5/2) silty clay, dark grayish brown (2.5Y 4/2) moist, stratified with thin layers of silty clay loam, clay loam, silt loam and fine sandy loam; many fine distinct gray (N 5/0) redoximorphic depletions and many fine prominent strong brown (7.5YR 4/6) redoximorphic concentrations; massive; hard, friable, slightly sticky and moderately plastic; common very fine roots throughout; many fine pores; few fine rounded white (10YR 8/1) nests of gypsum throughout; slightly effervescent; moderately alkaline; EC of 6; clear wavy boundary.

C3--46 to 60 inches; light brownish gray (2.5Y 6/2) silty clay, grayish brown (2.5Y 5/2) moist, stratified with thin layers of silty clay loam, clay loam, silt loam and fine sandy loam; many fine and medium distinct gray (N 5/0) redoximorphic depletions, many fine and medium distinct light olive brown (2.5Y 5/6) redoximorphic concentrations, and common fine prominent dark yellowish brown (10YR 4/6) redoximorphic concentrations; massive; hard, friable, moderately sticky and moderately plastic; common very fine roots throughout; many fine pores; few fine rounded white (10YR 8/1) nests of gypsum throughout; slightly effervescent; EC of 5.5; moderately alkaline.

TYPE LOCATION: Campbell County, Wyoming; about 900 feet east and 2300 feet north of the southwest corner of Sec. 9, T 75 N, R 55 W.; USGS Kline Draw, WY topographic quadrangle; lat. 44 degrees 45 minutes 23 seconds N. and long. 105 degrees 54 minutes 1 seconds W.

RANGE IN CHARACTERISTICS: The organic carbon content ranges from 1 to 3 percent in the A horizon and from 0 to 3 percent in the C horizon and decreases irregularly with depth. Depth to continuous accumulations of carbonates is 0 to 10 inches. The average exchangeable sodium ranges from 0 to 10 percent, but some pedon have subhorizons that are greater than 10 percent. Redoximorphic features are common in the upper 18 inches. The average annual soil temperature is 47 to 50 degrees F.

The A horizon has hue of 5Y, 2.5Y or 10YR, value of 4 to 7 dry and 3 to 5 moist, and chroma of 1 to 3. Texture is clay loam, loam, silt loam, silty clay loam, silty clay or clay. Reaction is neutral to moderately alkaline. The EC is 0 to 4 mmhos/cm and the calcium carbonate equivalent is 0 to 5 percent. Some pedons have an AC horizon.

The C horizon has hue of 5Y, 2.5Y or 10YR, value of 5 to 7 dry and 3 to 5 moist, and chroma of 1 to 4. Texture is silty clay, clay, clay loam or silty clay loam, stratified with very fine sandy loam, fine sandy loam, sandy loam, loam, silt loam or loamy fine sand. In some pedons it has accumulations of carbonates, gypsum or salts. Reaction is slightly alkaline to strongly alkaline. The EC is 2 to 8 mmhos/cm and the calcium carbonate equivalent is 1 to 12 percent.

COMPETING SERIES: These are the Abbott and Apishapa series. The Abbott series have and EC of more than 8 mmhos/cm throughout. In addition, the Abbott soils occur in locations with 11 inches or less of annual precipitation. Apishapa soils average more than 2 percent gypsum in the lower part of the particle-size control section. In addition, Apishapa soils occur in areas that a frost-free season of more than 135 days.

GEOGRAPHIC SETTING: Boruff soils are on flood plains and low stream terraces. They formed in stratified recent alluvium derived from mixed sedimentary sources. Slopes are 0 to 3 percent. Elevations are 3,500 to 5,000 feet. The mean annual precipitation ranges from 10 to 19 inches, half of which falls as rain or snow from March through June. The mean annual air temperature ranges from 44 to 50 degrees F. The frost-free season is about 105 to 130 days.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Bidman, Clarkelon, Deekay, Draknab, Forkwood, Haverdad, Iwait, Jaywest, Kishona, Moorhead, Rockypoint and Ulm soils. These soils are all on higher lying fans or terraces. They are all better drained than the Boruff soils. In addition, Bidman, Deekay, Forkwood, Jaywest, Moorhead and Ulm soil have argillic horizons; Clarkelon soils are coarse-loamy; Draknab soils are sandy; and Iwait and Kishona soils do not have stratified horizons.

DRAINAGE AND PERMEABILITY: Poorly and somewhat poorly drained; slow runoff; slow permeability. These soils are subject to rare to frequent flooding for very brief or brief periods during prolonged, high intensity storms in the spring and early summer. A seasonal high water table is at a depth of 0.5 to 1.5 feet at some time during the period April through July.

USE AND VEGETATION: These soils are utilized primarily as rangeland and wildlife habitat. The native vegetation is mainly green needlegrass, bearded wheatgrass, slender wheatgrass, western wheatgrass and cottonwoods. Indian saltgrass, alkali sacaton, sedges and willows.

DISTRIBUTION AND EXTENT: North-eastern Wyoming and possibly south-eastern Montana. These soils are of limited extent.

MLRA OFFICE RESPONSIBLE: Bismarck, North Dakota.

SERIES ESTABLISHED: Crook County, Wyoming (Correlation Amendment); 2003.

REMARKS: Diagnostic horizons and features recognized in this pedon are: ochric epipedon - 0 to 2 inches (A horizon); aquic moisture regime - redoximorphic concentrations and chroma of 2 in 40 to 50 cm layer; vertic subgroup criteria - LE of more than 6 in the top meter.

ADDITIONAL DATA: S98WY005-010, type location.

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