SECTION 20 COMPLIANCE ANALYSIS FOR CBNG PRODUCED WATER DISCHARGES BY THE TERMO COMPANY TO BITTER CREEK, CAMPBELL COUNTY, WYOMING

KC HARVEY

Soil & Water Resource Consulting

AN ENERCREST COMPANY

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1.0 INTRODUCTION

This report presents an assessment of potential impacts to agricultural practices along Bitter Creek and defines proposed effluent limits for the discharge of coalbed natural gas (CBNG) produced water to Bitter Creek. The discharge of produced water will be from The Termo Company's (Termo) Homestead Draw II project to Bitter Creek. Bitter Creek, located in Campbell County, Wyoming, is an ephemeral stream that flows north-northwest and drains into the Powder River. An ephemeral drainage is defined as a drainage that only contains water during and immediately after some precipitation or snowmelt events (Ward and Trimble, 2004) therefore the channel is periodically dry.

This assessment incorporates a Tier 2 – Background Water Quality Analysis approach to demonstrate compliance with Chapter 1, Section 20 of the Wyoming Water Quality Rules and Regulations, which state:

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

The Tier 2 – Background Water Quality Analysis approach proposes effluent limits as equal to or less than that of background water quality conditions. To obtain estimates of background water quality on ephemeral stream channels such as Bitter Creek, soil sampling and analysis is conducted to obtain the soil electrical conductivity (EC) of fields historically irrigated, naturally or artificially, along the subject stream. In this analysis, water quality estimates calculated from soil sample analyses are compared to Bitter Creek water samples collected in May of 2007 by SWCA Environmental Consultants. The more conservative Bitter Creek water quality estimate derived from soil EC was applied to the effluent limits proposed in this analysis.

The second part of the Tier 2 analysis provides an interpretation of soil samples within fields that are hydraulically isolated from Bitter Creek but could receive irrigation from Bitter Creek during some runoff events. A streamflow characterization of Bitter Creek, hydraulic assessment of the subject fields, and mixing analysis are presented to demonstrate that the proposed effluent limits will not negatively affect the water quality applied to these fields during significant runoff events.

Prior to this Section 20 compliance analysis submission, data collection from the Bitter Creek Drainage was completed by SWCA Environmental Consultants of Sheridan, Wyoming (SWCA) and BKS Environmental Associates of Gillette, Wyoming (BKS) between June 8 and August 30, 2007 and incrementally submitted to the WDEQ as results became available. Upon gaining landowner permission, additional data has been collected in December of 2007 by KC Harvey, Inc. (KC Harvey) at previously unsampled locations in the Bitter Creek drainage. This report constitutes a resubmission and analysis of all data previously collected at Bitter Creek including data collected by KC Harvey in December of 2007 (Table 1).

To identify representative areas suitable for soil sampling, 10 miles of the Bitter Creek stream channel were investigated for the presence of naturally and/or artificially irrigated areas. Naturally irrigated soils are often located on floodplain landscape positions, usually immediately adjacent to the primary channel. These areas consist of distinct vegetation communities and densities which indicate they receive more water than the surrounding landscape, where precipitation is the only water source. This additional water received by naturally irrigated soils is due to occasional flooding or the existence of a fluctuating high water table, with Bitter Creek being the primary source for both. According to a search of the Wyoming State Engineer's Office water rights database, there are no permitted irrigation diversions on Bitter Creek downstream of the Termo CBNG discharges.

2.0 Chronology of Bitter Creek Soil Sampling Efforts

Limited by site access permissions, the initial soil assessment conducted by SWCA (June 11, 2007) resulted in the identification of suitable soil sampling locations within state owned lands in Township 57N, Range 74 W Section 36. Sampling locations were divided into three zones based on their geomorphic setting, hydrologic regime and elevation relative to the Bitter Creek channel bottom (Figure 1, Table 1; Locations 3 through 5). "Zone 1 was adjacent to the stream channel where relatively flat, dry ground was present that could produce useable grass" (SWCA, 2007a). Of the 12 locations sampled within Section 36 by SWCA, only two sites were identified as characteristic of "Zone 1." "Little of this type of terrain (Zone 1) was found in the study areas because Bitter Creek has a deeply incised channel ... with few flat depositional areas" (SWCA, 2007a). Zones 2 and 3 were described by SWCA as located on the first and second terraces above the stream channel and account for the remaining 10 soil sampling locations. Samples collected from each respective zone were composited by zone to represent differences in soil physicochemistry inherent to their landscape position. Based on photographic and narrative descriptions, and KC Harvey's visual review of Bitter Creek fluvial-geomorphology at the 10 soil sampling locations within Zones 2 and 3, the likelihood that soil samples within Zones 2 and 3 reflect background Bitter Creek water quality is questionable. To reflect uncertainties in the merit of data collected in

Zones 2 and 3, KC Harvey calculated historic water quality of Bitter Creek with these data and discovered that the estimated historic Bitter Creek water quality was actually greater when Zone 2 and 3 data were incorporated. Due to the uncertain nature of this data it was decided to exclude the Zone 2 and 3 data (Figure 1; Table 1; Locations 4 & 5) from the Tier 2 analysis. Data collected from within Zone 1 is considered very applicable to this compliance analysis and were included in all water quality calculations (Figure 1; Table 1; Location 3).

As per WDEQ request, additional soil samples were collected by SWCA on July 25, 2007 to further compliment the previously collected dataset. Again, limited by site access permissions, soils data were collected in Township 57N Range 74W Sections 16 and 22. Four appropriate locations were identified (Figure 1, Table 1; Locations 8 - 10). The second submission of Bitter Creek soils data to the WDEQ (August 10, 2007; SWCA, 2007b) included a soils assessment conducted by BKS in Township 56N Range 74W Section 13 on land owned by Robert Brug (Figure 1, Table 1; Locations 1 and 2). Each of the locations sampled by BKS are described in the August 10, 2007 Section 20 submission as unlikely to receive exposure to waters from Bitter Creek and furthermore were not analyzed for electrical conductivity. This dataset is disclosed in Table 1 but could not be incorporated into calculations for approximating the background water quality of Bitter Creek due to the lack of EC data. Furthermore, this data should not be used to estimate background water quality since it was clearly stated that the areas sampled were unlikely to receive water from Bitter Creek.

After reviewing the second submission, the WDEQ again felt that additional data collection was warranted. On August 30, 2007, SWCA collected a third set of soil samples along functioning spreader dikes in Township 57N Range 74W Section 8 (Figure 1, Table 1; Locations 11a through 11l). Due to the presence of alfalfa on location, samples were collected to a depth of 72 inches at 12 locations within areas assumed to be irrigated by the spreader dikes. The soil samples were collected as discrete locations and not composited across the field, therefore these small areas contain a total of 12 samples.

Subsequent surveying and hydrologic assessments of locations 11a through 11l performed in December of 2007 (Figure 2) by Lowham Engineering, LLC (Gillette, WY), as well as interpretations of soil EC data from locations 11a through 11l suggests that conditions resulting in the initiation of irrigation at these artificially irrigated areas are distinct from those initiating irrigation at upstream naturally irrigated areas. The analysis furthermore suggests the initiation of irrigation at these artificially irrigated spreader dike areas and the resulting soil physicochemistry are dependent on 1) low reoccurrence interval Bitter Creek flow regimes 2) hydraulic isolation from Bitter Creek under normal flow regimes, 3) the influence of run-on from the surrounding landscape not associated with Bitter Creek (Figure 3), and 4) a suite of discharge chemistries distinct from those influencing naturally irrigated fields upstream at soil sampling Locations 1 through 10.

The section "Characterization of the Hydraulically Isolated Fields" below is devoted to describing the bodies of evidence which substantiate these hypotheses. A mixing analysis is presented to estimate the water quality of Bitter Creek under runoff events that could initiate irrigation to these flood irrigation areas in the presence of CBNG waters.

In December of 2007, landowner permission was secured to sample private land within Township 57N Range 74W Sections 23 and 26. Of the eight potential spreader dikes identified by aerial photography, on-site inspection by KC Harvey indicated five spreaders were breached and one physically incapable of diverting water over-bank. Due to the presence of alfalfa, flood irrigated areas associated with the remaining two intact spreader dike areas were sampled to a depth of 72 inches and combined into a single sample, composited by depth (Figure 1, Table 1; Location 6). Based on vegetation and hydrologic indicators, an additional area was identified as receiving natural irrigation from Bitter Creek (Figure 1, Table 1; Location 7). The presumption of natural irrigation at this location was confirmed during sampling by subsurface saturated soil conditions within six feet of the soil surface.

The analysis presented herein will demonstrate whether produced water discharged by Termo into Bitter Creek will result in degradation of background water quality leading to a measurable decrease in crop and/or livestock production. As mentioned previously, water quality data collected from Bitter Creek in May of 2007 by SWCA Environmental Consultants was also incorporated into this analysis.

3.0 Delineation of Hydraulically Isolated Fields

As a result of a field visit by KC Harvey and Lowham Engineering to the Oedekoven flood irrigation areas on December 6th 2007, it was determined that the ability to correctly interpret soils data collected by SWCA at sampling locations 11a-l was impeded by a lack of understanding of the path that water takes through the spreader system. In the absence of this understanding, it was difficult to determine with certainty which soil sampling locations had historically received Bitter Creek flood irrigation waters within the Oedekoven spreader dike system and which had not.

3.1 Description of Irrigation System

During December 2007, Lowham Engineering, LLC (Lowham) surveyed the Oedekoven fields and produced a one-foot topographical map with irrigation inundation boundaries (Figure 2). The topographic map was then used to estimate the hydraulic attributes of the identified artificial irrigation areas located in Township 57N Range 74W Section 8. During the initial field visit by KC Harvey and Lowham on December 6th, two distinct features were identified for surveying, these included an on-channel spreader dike with a headgate structure and associated reservoir basin, and three potential irrigated areas with spreader dikes (Figure 2).

The on-channel spreader dike and headgate are used to prohibit Bitter Creek flow from passing through a culvert and backs Bitter Creek water up into the reservoir basin. The backed up water then fills the reservoir basin until reaching a 12 inch culvert which conveys water onto the flood irrigation areas (Culvert 1, Figure 2). The survey completed by Lowham Engineering indicates that the water level would have to be raised by approximately eight feet before irrigation could be initiated through Culvert 1. Based on the reservoir topography, approximately 41.42 acre-feet of water must be stored in the reservoir basin before irrigation could occur (Table 2) (Lowham Engineering, 2008). Lowham Engineering's surveying of the Oedekoven fields indicates that these fields are hydraulically isolated from Bitter Creek and cannot be artificially irrigated without the headgate structure being closed.

Once irrigation is initiated, the irrigation water will flow into Area 1 and could potentially irrigate up to approximately 4.7 acres (green hashed lines, Figure 2). The area irrigated could be decreased to approximately 2.5 acres (blue hashed lines, Figure 2) if Culvert 3 is unobstructed. Area 1 has a spillway at the northwestern edge of the spreader dike that allows water to flow into Area 2 once the water ponds to a sufficient elevation (approximately 3,646 feet) (Figure 2). Water could also be released into Area 2 if Culvert 3 (elevation 3,642.9 feet) was not obstructed (Figure 2). It should be noted that Culvert 2 can not allow water to pass from Area 1 to Area 3 since the bottom culvert 2 is 1.6 feet higher (3,647.6 feet) than the Area 1 spillway elevation (3,646 feet) (Figure 2). Therefore, it is not possible for water to be diverted through Culvert 2 into area 3 under any circumstances. Since water flow through Culvert 2 into Area 3 is not possible it is assumed that Area 3 is not irrigated artificially by the headgate system.

Area 2 can be irrigated by water from Bitter Creek after the water has passed through Area 1 as described above. Irrigation in Area 2 can be performed on approximately 12.7 acres if both Culvert 4 and Culvert 5 are obstructed. Water would then be released over a spillway and migrate to a small settling basin before returning to Bitter Creek through a six inch steel pipe (Figure 2). If Culvert 4 and Culvert 5 are left unobstructed then approximately 2.2 acres could be irrigated.

As mentioned above, irrigation at the Oedekoven fields can only be initiated when the headgate is closed and greater than 41.42 acre-feet of water has flowed into the reservoir basin. To determine the frequency at which to expect at least 41.42 acre-feet of water to reach the Oedekoven headgate, Lowham Engineering (2008) estimated the streamflow characteristics for the Bitter Creek watershed above the point of diversion (headgate) (Table 3). The streamflow characteristics were calculated using methods published by Miller (2003) and Craig and Rankl (1978). Based on streamflow characteristics calculated by Lowham Engineering (2008) and the fact that Bitter Creek is an ephemeral stream, irrigation will only be initiated during a significant storm event or series of storm events (Table 3). In other words, in the absence of rainfall or snowmelt events there is not enough flow in Bitter Creek to produce the 41.42 acre-feet of water to initiate irrigation. To fill the reservoir basin with enough water to initiate irrigation a 10 year storm event or a series of smaller (i.e. 5 year events) would be required (Table 3).

3.2 Description of Soils

As previously introduced, soil samples were collected by SWCA on August 30, 2007 within the Oedekoven fields to assist in estimating background water quality of Bitter Creek (Table 1). The sample locations are shown on Figure 2, labeled 11a through 11l. Of the twelve samples collected by SWCA, seven sample points were located outside the areas that could be irrigated with water that flows from Bitter Creek through Culvert 1 (Figure 2). Sample 11f is located in Area 3 and is less than five feet above the elevation of the Bitter Creek stream bottom. Due to its proximity to Bitter Creek and low relative elevation above Bitter Creek, the soil chemistry of sample 11f is influenced by natural irrigation. Surface soil salinity is expected to be impacted by groundwater quality if the groundwater is less than five feet from the soil surface (Hanson et al., 1999). Therefore data from soil sampling location 11f have been included the Tier 2 calculations of background Bitter Creek water quality.

Samples 11b, 11c, 11h, 11i, and 11j are in close proximity to Area 1 but are at least eight feet higher in elevation than Bitter Creek and greater than 300 feet from the channel periphery (Figure 2). Bitter Creek is an ephemeral drainage (i.e. losing stream) which indicates that the water table likely increases in depth as the distance from the stream channel increases. Although groundwater elevation information is not available from the Oedekoven area it is estimated that the groundwater table is at least eight feet below the ground surface at locations 11b, 11c, 11h, 11i and 11j. Surface soil salinity is not expected to be impacted by groundwater quality if the groundwater is greater than five feet from the soil surface (Hanson et al., 1999). Therefore, the EC of soil samples 11b, 11c, 11h, 11i and 11j are not influenced by Bitter Creek water, precluding their ability to estimate historic, background Bitter Creek water quality.

Based on the survey conducted by Lowham (2008), soil sample 11l is near Area 2 and is at least seven feet above and two tenths of a mile from Bitter Creek (Figure 2). For reasons identical to those pertinent at locations 11b, 11c, 11h, 11i, and 11j, soil sample 11l cannot be influenced by Bitter Creek water. Locations 11b, 11c, 11h, 11i, 11j and 11l are considered to operate under dry land conditions.

The soil samples located within the "green hashed" boundaries on Figure 2 are seasonally influenced by Bitter Creek water that flows through Culvert 1 (including sample locations 11a, 11d, 11e, 11g and 11k) and are considered to be artificially irrigated. To determine whether these samples should be used in the Tier 2 analysis, the EC of the Oedekoven artificially irrigated soil sample locations were statistically compared to the EC of the Oedekoven dry land soil sample locations and also to the soil sample EC data collected from the naturally irrigated areas (locations 3-10 and 11f).

It was determined that the EC of the artificially irrigated soil sample locations was not statistically different from the EC of the dry land soil sampling locations at an alpha of 0.05. In other words, the mean EC inside the Oedekoven artificially irrigated areas (11a, 11d, 11e, 11g and 11k) was statistically equivalent to the mean EC outside of the artificially irrigated areas (11b, 11c, 11h, 11i, 11j and 11l). However, when the EC of the artificially irrigated soil sample locations (11a, 11d, 11e, 11g and 11k) were compared to the naturally irrigated soil sample locations (locations 3-10 and 11f), the mean EC values were significantly different at an alpha of 0.05.

Based on the available soils data, this indicates that the population of soil EC's within the Oedekoven artificially irrigated areas are equivalent to those receiving no irrigation whatsoever, but distinct from the population of soil EC's within Bitter Creek's naturally irrigated soils. This statistical distinction indicates that the EC of the artificially irrigated soils has not been influenced by Bitter Creek water under the same circumstances as the naturally irrigated areas. As a result, data from the artificially irrigated soil sample locations (11a, 11d, 11e, 11g and 11k) were excluded from calculations to determine the historic background water quality of Bitter Creek. This conclusion is supported by review of the 2002 color infrared aerial photographs of the area (Figure 4) and anecdotal evidence from the landowner's employee (Bruce Amende) who communicated he had only observed artificial irrigation at the spreader dikes twice since 1980 (SWCA 2007c).

If WDEQ truly thinks that these data can be used for estimating Bitter Creek water quality, the data from artificially irrigated soil sampling locations 11a, 11d, 11e, 11g and 11k (within the green area on Figure 2) should be averaged by irrigation area and the average value should be used as part of the Tier 2 analysis. If the data are not averaged, these areas would be considered "oversampled" compared to the rest of the Bitter Creek drainage and would bias the resulting analysis.

The majority of soil sample locations in irrigation areas 1 and 2 collected in association with the Oedekoven fields fall within the Moorhead series boundary. The Moorhead soil series is described as very deep well drained soils formed in alluvium derived from shales (National Cooperative Soil Survey, 2005). In the official soil series description of the Moorhead soils it is noted that the electrical conductivity ranges from 0 to 4 dS/m (Appendix A). For Moorhead soils occurring in northern Campbell County, Wyoming, NRCS chemical soil property data lists soil salinity ranging from 0.0 to 2.0 dS/m for this series (Appendix A). The low salinities associated with the dominant soil series, in conjunction with the low salinities observed in the sample data indicate that soils in

Areas 1 and 2 are most likely in their native state and should not be used to estimate Bitter Creek water quality.

Other soil series associated with artificially irrigated areas 1 and 2 are also characterized by low salinity, as indicated by NRCS chemical soil property data for Northern Campbell County (Appendix A). The Fairburn, Samsil, Badland, Muleherder, and Ironbutte series possess low soil salinities, ranging from 0.0 to 2.0 dS/m. These reported low electrical conductivities are similar to the actual electrical conductivities measured in the soil samples obtained by SWCA, again indicating that soil chemistries in areas 1 and 2 remain in a relatively natural state.

3.3 Potential Impacts to Hydraulically Isolated Fields

To ensure that the proposed end-of pipe EC limits are protective of the Oedekoven hydraulically isolated areas, a mixing analysis was conducted to estimate Bitter Creek water quality during periods that could initiate irrigation at the Oedekoven flood irrigation areas. The mixing analysis was performed using PHREEQC (USGS, 2005) on multiple assumed water qualities so that a range of conditions could be evaluated.

By examining the magnitude of precipitation events associated with different storm reoccurrence intervals in the Bitter Creek watershed it is evident that a wide range of runoff volumes can be expected (Table 3). Lowham (2008) predicts that storm events in the Bitter Creek watershed can produce between 10.8 acre-feet and 137.8 acre-ft of runoff depending on the reoccurrence interval. As stated previously, storm events or a series of storm events producing greater than 41.42 acre-feet of runoff are required to initiate irrigation at the Oedekoven spreader dikes (Lowham Engineering, 2008). The minimum single storm event capable of producing 41.4 acre feet of runoff is a 10 year event (Table 3). As a result, characteristics of the Bitter Creek 10 year precipitation-runoff event were used in this mixing analysis.

Using GIS, it was determined that approximately seven percent of the Bitter Creek watershed acreage can contribute runoff waters to upstream Termo tributary CBNG reservoirs (Figure 5). Under the most conservative scenario, runoff waters contributing to CBNG reservoirs will evacuate the entire volume of each tributary reservoir assumed to be at its CBNG storage capacity. This situation would result in a discharge of CBNG water to Bitter Creek equivalent to the volume received by runoff. This is anticipated to contribute approximately seven percent of the storm runoff waters produced in the Bitter Creek watershed. Therefore it was assumed that during runoff events a mixing ratio of 93:7 (93 percent rainfall runoff and seven percent CBNG produced water) is appropriate. In other words 93 percent of the water volume available as storage behind the headgate would reflect the water chemistry associated with natural Bitter Creek runoff, unaffected by CBNG water, and seven percent of the runoff would have characteristics associated with CBNG produced water chemistry.

Although natural runoff water quality is unknown, a few "opportunity" samples were collected from Bitter Creek during May of 2007 (Appendix B). These data were evaluated in the mixing analysis. To provide a degree of sensitivity, a theoretical runoff water of high quality was also incorporated into the mixing analysis. The theoretical water chemistry was developed by using the opportunity water samples and systematically lowering the concentrations of dissolved constituents. This resulted in a water chemistry with an ECw of 1.3 dS/m (note that according to soil salinity-crop yield data, runoff irrigation waters with an ECw of 1.3 dS/m would have no impact to alfalfa yields). It is assumed that any addition of CBNG produced water exhibiting an ECw greater than 1.3 dS/m would result in an increase to the EC of this theoretical water quality.

Three separate scenarios were modeled using PHREEQC to determine if CBNG produced water released during storm events would negatively impact runoff water quality used to irrigate Oedekoven flood irrigation areas. The first scenario mixed Bitter Creek water chemistry measured in May of 2007 (Bitter Creek Water 1) with the estimated CBNG produced water chemistry (Produced Water 1) (Table 4). The model indicated that the addition of seven percent CBNG produced water to measured Bitter Creek chemistries would slightly improve the ECw of runoff waters available to irrigate Oedekoven spreader dike areas (Column 9, Table 4). Under Scenario 1, the irrigation waters would be improved, resulting in no negative impacts on crops grown in the hydraulically isolated fields.

The second modeled scenario combined 93 percent of the theoretical, high quality Bitter Creek water with an ECw of 1.3 dS/m (Bitter Creek Water 2) with seven percent of the estimated CBNG produced water (Produced Water 1). The model indicated a very slight increase in ECw (< 0.04 dS/m), which resulted in a mixed water ECw of 1.3 dS/m when rounded to the tenths (Column 11, Table 4). This scenario indicates that any natural runoff water plus CBNG produced water applied to the hydraulically isolated fields would have no negative impact on crop production with respect to salinity.

The last scenario blended theoretical Bitter Creek water with an ECw of 1.3 dS/m (Bitter Creek Water 2) and a simulated CBNG produced water with an ECw equal to the end of pipe effluent limit proposed later, in Section 6 of this report (Produced Water 2) (Column 13, Table 4). The results of this mixing model demonstrate that the mixed water ECw will increase approximately 0.2 dS/m from 1.3 dS/m to 1.5 dS/m (Table 4). The following equation is a frequently cited relationship that relates irrigation water quality to the soil ECe:

$$ECe = 1.5 \times ECw.$$

Where ECe is the average EC of the soil (measured in a saturated paste extract), and ECw is the long-term average EC of the applied water (Ayers and Westcot, 1985). Scenario 3 produces Bitter Creek runoff waters with an ECw of 1.5 dS/m, suggesting that soils in equilibrium with this water chemistry would have a resulting root zone ECe of 1.5 * 1.5, or 2.25 dS/m. Using alfalfa salinity thresholds published in Hanson et al. (1999), an ECe of 2.25 is greater than the maximum root zone salinity at which 100 % yield occurs, a value placed at ECe = 2.0 dS/m. To calculate the relative yield of alfalfa at an ECe of 2.25 dS/m, the following equation is used (Hanson et al. 1999):

$$Y = 100 - B(ECe-A)$$

Where Y = the relative yield or yield potential (%), A = the maximum root zone salinity at which 100 % yield occurs in dS/m (2.0 dS/m for alfalfa) and B = the slope of the yield reduction line (% reduction in relative yield per increase in soil salinity, dS/m), which equates to 7.3 for alfalfa (Hanson et al. 1999). By substituting alfalfa specific values for A, B and the ECe determined in Scenario 3, we see that under Scenario 3, alfalfa will grow at 98 % of its relative yield potential with a mixed water quality ECw of 1.5 dS/m.

$$Y = 100 - 7.3(2.25 \text{ dS/m} - 2 \text{ dS/m})$$
$$Y = 98.2\ \%$$

This scenario indicates that any natural runoff water plus CBNG produced water applied to the hydraulically isolated fields would have minimal negative impacts to alfalfa production with respect to salinity.

4.0 Baseline Conditions of Bitter Creek

4.1 Soils

4.1.1 NRCS Soil Mapping Units

The Natural Resource Conservation Service (NRCS) Campbell County soil survey contains soil maps for the entire Bitter Creek drainage (Figures 6 and 7). Several different soil map units are present within soil sample locations associated with the Tier 2 analysis, Locations 1 through 10 and 11f, most notably the Rockypoint-Boruff Complex. The official NRCS descriptions for the Rockypoint and Boruff soil series are included in Appendix A.

Rockypoint soils consist of very deep, well drained soils formed in recent alluvium derived from mixed sedimentary sources. Rockypoint soils are generally found on flood plains and low terraces with slopes of 0 to 6 percent. Clay percentages usually range between 15 to 35 percent, mean annual precipitation is about 15 inches. Rockypoint soils are moderately permeable. 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 (National Cooperative Soil Survey, 2005).

Boruff soils consist of very deep, poorly and somewhat poorly drained soils formed in alluvium on flood plains and low stream terraces with slopes of 0 to 3 percent. Clay percentages typically range from 35 to 60 percent. Boruff soils receive approximately 14 inches of precipitation annually and are characterized as having slow permeability. 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 (National Cooperative Soil Survey, 2005).

4.1.2 Soil Sampling and Analysis Methods

The extent of literature available to KC Harvey concerning the soil sampling methodologies used by SWCA and BKS to collect data in the Bitter Creek drainage are limited to the contents of previously submitted Section 20 documents to the WDEQ dated June 28, August 10 and September 12, 2007 (SWCA, 2007a; SWCA, 2007b; SWCA, 2007c). The sampling methodologies for these sampling events have already been presented to the WDEQ (SWCA, 2007a; SWCA, 2007b; SWCA 2007c).

On December 6, 2007, KC Harvey soil scientists collected soil samples from three previously unsampled fields within the Bitter Creek drainage. Two of the areas were likely irrigated due to unpermitted spreader dikes while the third identified location was naturally irrigated directly from Bitter Creek. The previously unsampled areas were located on property owned by the Crockett Cattle Company. These locations had not been sampled previously due to landowner access issues.

Due to the small aerial extent of spreader dike fields and their relatively close proximity, they were grouped into one field. Six locations were sampled in the spreader dike fields and composited by depth. Six samples were also collected within an unswathed swale subject to natural irrigation. A handheld global positioning system (GPS) marked each sampling location. At each sample location, soil samples were collected from six depth increments; 0 to 12, 12 to 24, 24 to 36, 36 to 48, and 48 to 60 and 60 to 72 inches using a truck-mounted Giddings Probe (Giddings Machine Company, Windsor, Colorado). Samples were then composited by depth across all sampling locations for a total of six samples representative of the spreader dike fields and six representative of the naturally irrigated swale. Subsequent analysis at Energy Laboratories, Inc. (Helena, Montana) included measurements of the following soil parameters:

- pH,
- electrical conductivity (EC),
- dissolved calcium,
- dissolved magnesium,
- dissolved sodium,
- sodium adsorption ratio (SAR),
- saturation percentage,
- extractable sodium
- exchangeable sodium,
- exchangeable sodium percentage (ESP),
- cation exchange capacity (CEC),
- texture (percent sand, silt, and clay),
- percent lime,
- percent organic matter, bicarbonate, and
- sulfate

Soil data quality were assessed in accordance with PARCC procedures (EPA, 1998). The PARCC parameters; Precision, Accuracy, Repeatability, Completeness, and Comparability are all indicators of data quality. Data collection and validation methods that address these parameters ensure that data are of known and acceptable quality and are representative of the system sampled. Table 1 summarizes the entire soil data set for the Bitter Creek drainage collected by BKS, SWCA, and KC Harvey. Table 5 summarizes the data that meets the PARCC procedures and is suitable for estimating historic, background Bitter Creek water quality. The original laboratory results for the soil data set collected by KC Harvey is provided in Appendix C. As described in Section 2.0 soil sample data collected by BKS was not incorporated into the Tier 2 analysis due to the lack of EC data and that it was clearly stated that the sampling location were likely outside of areas that would be influenced by Bitter Creek water quality. Soil samples collected in Zones 2 and 3 were excluded from the Tier 2 analysis because Zones 2 and 3 were likely not influenced by Bitter Creek water quality (Section 2.0). Some of the data (sample locations 11b, 11c, 11h, 11i, 11j and 11l) from the Oedekoven fields were excluded from the Tier 2 analysis because they were outside the area of artificial irrigation and they were likely not influenced from by natural irrigation (Section 3.2). Sample locations located within the artificially irrigated areas (Figure 2) were excluded due to their lack of comparability to the known naturally irrigated areas (Section 3.2). Soil sample location 11f was used in the Tier 2 analysis because it is likely naturally irrigated with Bitter Creek water and was comparable to the other naturally irrigated datasets in terms of salinity.

4.1.3 Soil Physical Conditions

Soil physical properties affect aeration rates, water infiltration, water storage, and movement of water through the soil profile. Soil textures at Locations 3, 6 through 10 and 11f associated with the Tier 2 analysis are predominately silty clay loam, clay loam and silty clay. Clay content in samples from Locations 3, 6 through 10 and 11f range from 12 to 50 % across all depths, averaging 33 % (Table 5). Percent organic matter in the surface soil samples (0-12 inch) ranges from 2.2 to 7.3 percent (Table 5), which is typical of these soil types in the Powder River Basin.

Soil textures at locations 11a, 11d, 11e, 11g and 11k (within the maximum predicted extent of artificial irrigation) are predominately loam, sandy loam, clay loam, and silty clay loam. Clay content ranges from 10 to 47 percent across all depths (Table 1). Percent organic matter in the surface soil samples (0 to 12 inch) ranges from 2.6 to 3.5 percent (Table 1), which is typical of these soil types in the Powder River Basin.

4.1.4 Soil Chemical Conditions

Soil salinity is the amount of soluble salts in a soil often measured by using the electrical conductivity (ECe) of the saturated paste extract. Salinity is important because high salt levels make it difficult for plants to obtain water (Bohn et al., 1985). Soils with ECe values greater than 4.0 dS/m are classified as saline. However, lower ECe values (< 2.0 dS/m) can affect sensitive plants while salt tolerant plants are productive at ECe levels greater than 8 dS/m.

Soil EC ranged from 0.39 to 14.0 dS/m in the 0 to 48 and 0 to 72 inch depth increment samples at Locations 3, 6 through 10 and 11f applied to the Tier 2 analysis (no soil EC data for soil sampling locations 1 and 2 / locations 4 and 5 represent Zones 1 & 2 and were excluded) (Table 5). EC values of 10 dS/m or greater were measured in samples at Locations 6 and 8 (Table 5). The highest EC values were encountered at inconsistent depth increments throughout Locations 3, 6 through 10 and 11f. These values are comparable to those reported by the NRCS for the Rockypoint and Boruff soil series.

Due to the observed presence of alfalfa at soil sampling Locations 6, 7 and 11f average soil EC was calculated to a depth of 72 inches to assist in determination of background water quality. At the time of sampling, no alfalfa was observed at locations 3, 8, 9 and 10, and average soil EC was calculated to a depth of 48 inches. The average soil profile EC at Locations 3, 6 through 10 and 11f ranged from 2.6 to 10.4 dS/m along Bitter Creek (Table 5). With the exception of Location 9, all sampling locations have average soil EC values greater than 4.0 dS/m which classifies these soils as saline (Table 5). Only plants that are tolerant or moderately tolerant of soil salinity are well suited for growth on these fields.

Soil EC at sampling locations 11a, 11d, 11e, 11g and 11k (artificially irrigated locations) from 0 to 72 inches range from 0.32 to 3.81 dS/m compared to a range of 0.39 to 14.0 dS/m in the 0 to 72 inch depth increment samples collected from naturally irrigated locations (Locations 3, 6 through 10 and 11f). At artificially irrigated locations the highest EC values were usually encountered at depth increments between 24 and 48 inches.

Sodic soils are "nonsaline soils containing sufficient exchangeable sodium to adversely affect crop production and soil structure" (Soil Science Society of America, 2001). High levels of adsorbed sodium tend to disperse clay particles thereby sealing the soil. The result can produce clogged soil pores, hard surface crusts, reduced infiltration, reduced permeability, and reduced oxygen diffusion rates, all of which interfere with or prevent plant growth.

By definition, sodic soils are those that have an exchangeable sodium percentage (ESP) greater than 15 (Levy et al. 1998; Abrol et al., 1988; Evangelou, 1998; McNeal and Coleman, 1966; Sparks, 1995; Sumner et al., 1998; Shainberg et al., 1971; Soil Improvement Committee, California Plant Health Association, 2002). ESP is the amount of adsorbed sodium on soil exchange sites expressed as a percent of the cation exchange capacity (CEC) in milliequivalents per 100 grams of soil (meq/100 g):

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

Soil ESP values at naturally irrigated locations 6, 7 and 11f range from 0.1 to 25 percent to a depth of 72 inches. ESP values at naturally irrigated locations 1, 2, 3, 8, 9 and 10 range from 0.1 to 20 percent to a depth of 48 inches (Table 5). The average soil profile ESP ranges from 1.0 to 16.8 percent across Locations 1 through 3, 6 through 10 and 11f. Soils with mean profile ESP values greater than 15 percent exist naturally at Locations 6 and 8. When combined with the measured salinity, Locations 6 and 8 are considered saline-sodic (Table 5). Therefore, locations 6 and 8 are naturally limited for crop production because of the enriched salinity and sodicity.

Soil samples from artificially irrigated locations 11a, 11d, 11e, 11g and 11k are both non-saline and non-sodic in each depth increment measured, as indicated by low soluble salt content (EC less than 4 dS/m) and low exchangeable sodium content (mean profile ESP less than 15).

4.2 Vegetation

A vegetation assessment of the naturally and artificially irrigated areas was not conducted as part of this Tier 2 analysis. However based on reports completed by SWCA it appears that alfalfa is present in some of the irrigated fields sampled. KC Harvey also noted the presence of alfalfa in the fields that they sampled in December, 2007. KC Harvey was not able to complete a vegetation assessment due to the season of field work. Therefore for this analysis it is assumed that alfalfa is the most limiting crop grown in the drainage with respect to soil salinity.

4.3 Surface Water

Water quality monitoring is conducted monthly at the WQMS TRIB1 near the Wyoming-Montana border located in Township 58N Range 75W Section 23 on Bitter Creek by

SWCA Environmental Consultants (Appendix B). From July 30, 2003 until May 14, 2007 no flow was recorded in Bitter Creek at this station. On May 14, 2007 a flow of 1.32 cfs was measured at this station and a water quality sample was collected. The WQMS water quality sample exhibited an ECw of 3.43 dS/m. The WQMS sample was analyzed for a limited set of parameters and could not be used by PHREEQC in the mixing analysis presented above. An additional Bitter Creek water quality sample was collected on May 18, 2007 on land owned by the Fred and Mary Ann Oedekoven Family Trust. The water sample collected on May 18, 2007 exhibited an ECw of 8.17 dS/m (Appendix B).

5.0 CHARACTERIZATION OF CBNG DISCHARGES

The water management strategy for the Termo Homestead Draw II CBNG Project calls for water storage in on-channel reservoirs, located within tributaries to Bitter Creek. Releases to Bitter Creek will only occur when natural storm flows cause the on-channel tributary reservoirs to overflow or when the landowner requests the water. Termo has submitted complete documentation and specific locations of all reservoirs and outfalls as per WYDEQ permit application requirements. Appendix B provides the water quality from one of two existing outfalls within the Homestead II POD. As measured on September 28, 2007, the EC and SAR of the discharged produced water was 1.62 dS/m and 20.5, respectively.

6.0 PROPOSED EFFLUENT LIMITS AND IMP STANDARDS

The "Tier 2 – Background Water Quality" approach included in the current draft Section 20 Agricultural Use Protection Policy (WYDEQ, 2006) is used herein to estimate the long-term average runoff water EC in Bitter Creek and, in comparison to measured Bitter Creek water quality, derive a proposed effluent limit for EC using sample Locations 3, 6, 7, 8, 9, 10 and 11f. Thus, in this Tier 2 evaluation, the background water EC is estimated from the EC of soil samples collected from areas downstream of the proposed discharges receiving natural and artificial irrigation from Bitter Creek under low flow conditions. This derivation technique assumes that soil chemical conditions along Bitter Creek are in equilibrium with the low flow runoff water chemistry supplied by Bitter Creek over the long term. Therefore, soil chemistry, particularly soil EC, is a function of the long-term average water quality received by the soil. The following equation is a frequently cited relationship that relates irrigation water quality to the soil ECe:

$$ECe = 1.5 \times ECw.$$

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

$$ECw = ECe \div 1.5$$

The resultant equation, which is referenced in the current Section 20 Agricultural Use Protection Policy (WYDEQ, 2006), allows for the estimation of long-term average ECw of the applied water, given that soil data have been collected at a specific site. As discussed above, soil ECe data collected from Zones 2 and 3 in T 57N, R 74 W Section 36 (locations 4 and 5) are inappropriate for use in calculating long-term average runoff water ECw in Bitter Creek; therefore, calculations were applied to data from sample Locations 3, 6, 7, 8, 9, 10 and 11f which resulted in a mean ECe of 6.6 dS/m (Table 6). The estimated long-term water quality of Bitter Creek is approximately 4.4 dS/m (6.6 divided by 1.5).

Based on previous permits issued in the Powder River Basin of Wyoming, the WDEQ has provided a level of conservatism to effluent limits using statistical methods. While not specifically stipulated by the Section 20 Agricultural Use Protection Policy, the statistical methods used by the WDEQ include an outlier test, mean ECe, and 95% confidence intervals. To perform these tests one primary assumption must be made and that is that the collected data is normally distributed. Therefore, before any statistical analysis was performed, the data were analyzed using the SPSS software package (SPSS, 2001) to determine if the data were normally distributed. Based on this analysis, it was determined that soil EC data from Locations 3, 6, 7, 8, 9, 10 and 11f are normally distributed (Table 6). Since the data are normally distributed it is appropriate to use basic T based statistics for the analysis.

An outlier test was performed on the data from soil sample Locations 3, 6, 7, 8, 9, 10 and 11f using the SPSS software. The outlier test indicates that all of the data are acceptable for use. Since all of the data were acceptable, based on the outlier test, a mean ECe, standard deviation, and 95% confidence interval were calculated from the Tier 2 data (Table 5) using SPSS (SPSS, 2001). The average deviation, 95 percent confidence intervals of the data was calculated to be 3.0 and 5.5 dS/m, respectively (Table 6). Dividing the 95 percent lower bound soil ECe by 1.5 estimates the Bitter Creek water quality to be approximately 3.7 dS/m. Therefore, using the current WDEQ procedure, the proposed end-of-pipe effluent limit for ECw would be 3.7 dS/m (Table 6).

In addition to the end-of-pipe EC limit, it is proposed that any resultant WYPDES permit for CBNG discharge in this drainage include monitoring for compliance with an EC standard and the chemical relationship between EC and SAR at designated irrigation monitoring points (IMPs). The proposed EC standard at the IMP would be equivalent to the calculated average soil EC in the irrigated fields (6.6 dS/m) divided by 1.5 to estimate the allowable salinity in the stream water. The proposed EC standard would not be a compliance limit; instead it would represent the target water quality value that should be achieved at the IMP to protect irrigated fields.

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

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

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

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

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Table 1. Complete soil physicochemical dataset collected in association with the Bitter Creek Section 20 Compliance Analysis.

Dataset #	Original Name	TRS	Sampled By[1]	Collection Date	Sample Depth	pH	EC	Percent Sat	SAR	ESP	Ca	Mg	Na	Sand	Silt	Clay	Texture	OM	CEC	Na-Ext
					Inches	S.U.	dS/M	%	Unitless	%	meq/L			%			Unitless	%	meq/100g	
1	Brug 1, 4, 5 Comp	56N73WS13	BKS	6/8/2007	0-12	7.6		56.9	0.09	0.10	8.2	3.2	0.2	37	32	31	Clay Loam	4.2		
	Brug 1, 4, 5 Comp	56N73WS13	BKS	6/8/2007	12-24	7.8		43.8	0.73	0.49	3.9	2.1	1.3	39	32	29	Clay Loam			
	Brug 1, 4, 5 Comp	56N73WS13	BKS	6/8/2007	24-36	7.9		48.5	7.74	1.80	27.0	26.0	40.0	52	24	24	Sandy Clay Loam			
	Brug 1, 4, 5 Comp	56N73WS13	BKS	6/8/2007	36-48	8.1		51.9	8.53	1.70	28.0	24.0	43.0	44	27	29	Clay Loam			
2	Brug 2, 3 Comp	56N73WS13	BKS	6/8/2007	0-12	7.1		65.0	0.10	0.13	7.0	2.8	0.2	27	39	34	Clay Loam	3.7		
	Brug 2, 3 Comp	56N73WS13	BKS	6/8/2007	12-24	7.8		62.0	0.59	0.45	4.4	1.6	1.0	14	44	42	Silty Clay			
	Brug 2, 3 Comp	56N73WS13	BKS	6/8/2007	24-36	8.3		68.2	11.90	8.40	23.0	44.0	69.0	18	47	35	Silty Clay Loam			
	Brug 2, 3 Comp	56N73WS13	BKS	6/8/2007	36-48	8.5		67.2	10.30	9.80	23.0	46.0	60.0	17	48	35	Silty Clay Loam			
3	1A	57N73WS36	SWCA	6/11/2007	0-12	7.0	3.05	72.8	0.73	1.70	23.3	15.2	3.2	14	52	34	Silty Clay Loam	7.3	34.9	0.8
	1B	57N73WS36	SWCA	6/11/2007	12-24	7.5	5.63	49.4	4.10	5.40	27.4	30.1	21.9	38	34	28	Clay Loam		23.6	2.4
	1C	57N73WS36	SWCA	6/11/2007	24-36	7.5	4.78	50.6	3.50	5.90	25.8	23.4	17.5	30	42	28	Clay Loam		22.6	2.2
	1D	57N73WS36	SWCA	6/11/2007	36-48	7.4	5.30	37.8	3.80	7.00	27.9	27.2	20.2	49	29	22	Loam		20.1	2.2
4	2A	57N73WS36	SWCA	6/11/2007	0-12	7.3	0.69	52.5	0.83	1.70	3.4	1.8	1.3	21	47	32	Clay Loam	3.7	28.2	0.6
	2B	57N73WS36	SWCA	6/11/2007	12-24	7.6	4.72	47.3	5.10	6.20	20.1	19.5	22.8	27	43	30	Clay Loam		21.4	2.4
	2C	57N73WS36	SWCA	6/11/2007	24-36	7.9	8.46	52.4	9.30	14.00	18.3	48.1	53.3	22	44	34	Clay Loam		23.1	6.1
	2D	57N73WS36	SWCA	6/11/2007	36-48	7.9	8.51	47.0	8.60	13.00	21.8	44.5	49.2	26	42	32	Clay Loam		21.8	5.1
	2E	57N73WS36	SWCA	6/11/2007	48-60	8.0	8.60	43.7	13.00	20.00	17.1	33.9	65.2	40	35	25	Loam		18.9	6.5
	2F	57N73WS36	SWCA	6/11/2007	60-72	7.9	8.32	41.5	9.60	10.00	20.1	42.2	53.5	50	28	22	Loam		19.2	4.2
5	3A	57N73WS36	SWCA	6/11/2007	0-12	7.3	0.66	58.1	0.59	2.00	3.2	2.0	1.0	8	54	38	Silty Clay Loam	3.6	29.6	0.7
	3B	57N73WS36	SWCA	6/11/2007	12-24	7.7	3.45	60.4	3.10	6.50	15.3	18.6	12.5	<1	57	43	Silty Clay		21.6	2.2
	3C	57N73WS36	SWCA	6/11/2007	24-36	8.1	13.10	64.6	14.00	25.00	19.8	83.2	97.0	2	55	43	Silty Clay		16.8	10.5
	3D	57N73WS36	SWCA	6/11/2007	36-48	8.1	14.00	69.9	15.00	22.00	20.3	94.2	113.0	1	55	44	Silty Clay		22.3	12.9
	3E	57N73WS36	SWCA	6/11/2007	48-60	8.0	12.20	52.3	16.00	20.00	20.5	60.8	100.0	14	48	38	Silty Clay Loam		22.8	9.7
	3F	57N73WS36	SWCA	6/11/2007	60-72	8.0	11.00	55.4	14.00	20.00	18.5	55.3	83.3	18	42	40	Silty Clay		21.9	9.1
6	Crockett Field Sub 2	57N74WS28	KCH	12/6/2007	0-12	7.9	7.54	65.7	12.00	13.00	18.9	30.0	57.3	6	57	37	Silty Clay Loam	2.2	30.7	7.8
	Crockett Field Sub 2	57N74WS28	KCH	12/6/2007	12-24	8.2	11.80	63.0	17.00	18.00	18.2	40.9	94.6	8	60	32	Silty Clay Loam	1.1	25.8	10.8
	Crockett Field Sub 2	57N74WS28	KCH	12/6/2007	24-36	8.2	10.70	60.7	16.00	18.00	18.7	43.1	88.4	12	58	30	Silty Clay Loam	1.2	26.5	10.1
	Crockett Field Sub 2	57N74WS28	KCH	12/6/2007	36-48	8.0	7.60	63.0	12.00	14.00	18.5	31.3	58.6	12	56	32	Silty Clay Loam	1.3	25.0	7.2
	Crockett Field Sub 2	57N74WS28	KCH	12/6/2007	48-60	8.0	8.30	59.5	12.00	13.00	19.0	30.8	60.9	22	49	29	Clay Loam	1.2	25.2	6.9
	Crockett Field Sub 2	57N74WS28	KCH	12/6/2007	60-72	8.0	6.11	58.8	10.00	16.00	15.8	24.5	45.4	13	53	34	Silty Clay Loam	0.9	20.8	6.0
7	Crockett Field 4 & 5	57N74WS28	KCH	12/6/2007	0-12	7.4	1.35	65.0	1.80	2.90	4.6	4.3	3.0	10	52	38	Silty Clay Loam	3.6	29.1	1.1
	Crockett Field 4 & 5	57N74WS28	KCH	12/6/2007	12-24	7.8	6.38	55.0	9.00	14.00	18.6	26.0	42.5	12	56	32	Silty Clay Loam	1.9	22.1	5.4
	Crockett Field 4 & 5	57N74WS28	KCH	12/6/2007	24-36	8.3	8.92	59.3	16.00	18.00	15.1	39.0	82.7	18	54	28	Silty Clay Loam	1.3	27.8	10.0
	Crockett Field 4 & 5	57N74WS28	KCH	12/6/2007	36-48	8.3	8.87	61.0	16.00	21.00	15.1	34.0	77.8	16	56	28	Silty Clay Loam	1.4	22.8	9.8
	Crockett Field 4 & 5	57N74WS28	KCH	12/6/2007	48-60	8.1	7.82	54.3	13.00	15.00	17.7	32.4	65.4	22	52	26	Silt Loam	1.2	22.4	8.9
	Crockett Field 4 & 5	57N74WS28	KCH	12/6/2007	60-72	8.1	7.51	52.8	13.00	12.00	18.6	31.4	63.9	26	49	25	Loam	1.1	23.7	6.3
8	3A (Site4)	57N74WS22	SWCA	7/25/2007	0-12	8.0	11.60	73.7	14.00	13.00	21.1	46.7	83.3	11	52	37	Silty Clay Loam	4.7	39.0	11.3
	3B (Site4)	57N74WS22	SWCA	7/25/2007	12-24	7.9	10.50	90.5	14.00	20.00	19.7	43.7	78.7	6	54	40	Silty Clay		31.5	13.6
	3C (Site4)	57N74WS22	SWCA	7/25/2007	24-36	7.8	11.00	90.0	14.00	16.00	22.9	48.5	84.1	6	48	46	Silty Clay		27.4	12.0
	3D (Site4)	57N74WS22	SWCA	7/25/2007	36-48	7.8	8.66	85.2	9.70	18.00	20.6	32.2	49.6	6	48	46	Silty Clay		22.8	8.2
9	2A (Site3)	57N74WS22	SWCA	7/25/2007	0-12	8.1	2.73	68.4	13.00	12.00	3.3	3.7	23.7	4	57	39	Silty Clay Loam	3.9	35.5	5.9
	2B (Site3)	57N74WS22	SWCA	7/25/2007	12-24	8.0	3.39	43.5	5.40	6.10	14.8	8.9	18.7	34	46	20	Loam		22.5	2.9
	2C (Site3)	57N74WS22	SWCA	7/25/2007	24-36	8.2	2.00	46.7	7.00	7.70	4.7	3.4	13.9	27	51	22	Silty Loam		25.3	2.6
	2D (Site3)	57N74WS22	SWCA	7/25/2007	36-48	8.1	2.38	82.3	6.30	8.80	7.1	5.3	15.6	10	57	33	Silty Clay Loam		24.8	3.1
10	1A (Sites 1&2)	57N74WS22	SWCA	7/25/2007	0-12	7.8	7.45	84.7	8.10	8.20	22.9	28.9	41.8	11	51	38	Silty Clay Loam	3.2	32.9	5.4
	1B (Sites 1&2)	57N74WS22	SWCA	7/25/2007	12-24	7.8	5.74	75.0	8.20	8.00	13.2	17.6	32.2	16	45	39	Silty Clay Loam		40.9	5.7
	1C (Sites 1&2)	57N74WS22	SWCA	7/25/2007	24-36	7.9	7.16	81.2	7.40	13.00	20.8	31.2	37.8	6	44	50	Silty Clay		25.5	8.4
	1D (Sites 1&2)	57N74WS22	SWCA	7/25/2007	36-48	7.8	8.01	77.0	7.70	10.00	20.6	35.8	40.8	13	45	42	Silty Clay		28.0	8.1

Notes:
1. Soil samples were colected by BKS Environmental Associates, Inc. (BKS), SWCA Environmental Consultants (SWCA) and KC Harvey, Inc (KCH)
Abbreviations: TRS = Township, Range, Section; S.U. = Standard units; dS/m = decisiemens per meter; % = percent; SAR = Sodium adsorption ratio; ESP = Exchangeable sodium percentage; Ca = Calcium; Mg = Magnesium; Na = Sodium; CEC = Cation exchange capacity; EC = Electrical conductivity; OM = Organic matter; Na-Ext = Extractable sodium; Exch Na = Exchangeable sodium; meq/L = milliequivalents per liter; meq/100g = milliequivalents per 100 grams of soil.

Table 1. Continued.

Dataset #	Original Name	TRS	Sampled By[1]	Collection Date	Sample Depth (inches)	pH (S.U.)	EC (dS/m)	Percent Sat (%)	SAR (Unitless)	ESP (%)	Ca (meq/l)	Mg (meq/l)	Na (meq/l)	Sand (%)	Silt (%)	Clay (%)	Texture (Unitless)	OM (%)	CEC	Na Ext (meq/100g)	Exch Na (meq/100g)
11a	Oedek 1	57N74WS8	SWCA	8/30/2007	0-12	7.5	0.53	39.1	0.11	0.96	2.4	1.9	0.2	58	25	17	Sandy Loam	3.2	18.0	0.2	0.2
	Oedek 1	57N74WS8	SWCA	8/30/2007	12-24	7.9	0.47	40.4	1.96	2.56	1.4	1.1	2.2	30	45	25	Loam		20.5	0.6	0.5
	Oedek 1	57N74WS8	SWCA	8/30/2007	24-36	7.9	1.66	40.1	2.97	2.93	6.2	4.7	6.9	32	44	24	Loam		20.8	0.9	0.6
	Oedek 1	57N74WS8	SWCA	8/30/2007	36-48	7.9	1.09	29.9	2.09	2.05	4.2	2.8	3.9	65	20	15	Sandy Loam		12.6	0.4	0.3
	Oedek 1	57N74WS8	SWCA	8/30/2007	48-60	7.8	0.97	28.8	1.82	2.45	3.8	2.5	3.2	69	18	13	Sandy Loam		11.3	0.4	0.3
	Oedek 1	57N74WS8	SWCA	8/30/2007	60-72	7.9	1.08	28.4	1.90	2.62	4.0	3.1	3.6	85	5	10	Loamy Sand		8.7	0.3	0.2
11b	Oedek 2	57N74WS8	SWCA	8/30/2007	0-12	7.1	0.46	46.8	0.67	0.07	2.2	1.5	0.8	19	49	32	Silty Clay Loam	3.9	20.8	0.1	0.0
	Oedek 2	57N74WS8	SWCA	8/30/2007	12-24	7.7	0.43	60.3	1.56	1.92	1.6	0.9	1.7	7	57	36	Silty Clay Loam		27.9	0.6	0.5
	Oedek 2	57N74WS8	SWCA	8/30/2007	24-36	7.7	0.86	44.3	1.48	1.47	3.4	2.7	2.6	19	49	32	Silty Clay Loam		23.8	0.5	0.4
	Oedek 2	57N74WS8	SWCA	8/30/2007	36-48	8.0	1.00	54.2	1.34	1.59	3.5	4.4	2.7	5	49	46	Silty Clay		24.9	0.6	0.5
	Oedek 2	57N74WS8	SWCA	8/30/2007	48-60	7.9	1.33	44.9	1.45	1.81	4.8	6.2	3.4	15	51	34	Silty Clay Loam		19.8	0.5	0.4
	Oedek 2	57N74WS8	SWCA	8/30/2007	60-72	7.9	1.68	43.1	1.51	1.72	7.2	9.0	4.3	25	46	29	Clay Loam		19.0	0.5	0.3
11c	Oedek 3	57N74WS8	SWCA	8/30/2007	0-12	7.6	0.47	55.2	0.26	0.20	2.4	1.6	0.4	5	39	56	Silty Clay	2.4	37.2	0.1	0.1
	Oedek 3	57N74WS8	SWCA	8/30/2007	12-24	7.9	0.60	61.1	1.65	1.62	1.7	1.8	2.2	1	40	59	Clay		32.1	0.7	0.5
	Oedek 3	57N74WS8	SWCA	8/30/2007	24-36	7.6	3.31	62.4	1.77	3.67	20.6	14.8	7.5	<0.1	47	58	Clay		32.7	1.0	0.6
	Oedek 3	57N74WS8	SWCA	8/30/2007	36-48	7.6	2.12	59.5	4.06	3.49	7.3	5.4	10.2	6	43	51	Silty Clay		34.5	1.8	1.2
	Oedek 3	57N74WS8	SWCA	8/30/2007	48-60	7.6	1.67	62.0	5.72	5.26	4.4	3.3	11.2	1	47	52	Silty Clay		33.9	2.5	1.9
	Oedek 3	57N74WS8	SWCA	8/30/2007	60-72	7.7	2.43	62.2	6.50	6.39	5.6	5.0	14.9	1	49	50	Silty Clay		33.8	3.1	2.2
11d	Oedek 4	57N74WS8	SWCA	8/30/2007	0-12	7.6	0.47	46.1	0.39	0.14	2.1	1.9	0.5	22	47	31	Clay Loam	3.5	24.0	0.1	0.0
	Oedek 4	57N74WS8	SWCA	8/30/2007	12-24	7.7	1.34	44.1	2.87	3.25	4.4	3.7	5.8	25	43	32	Clay Loam		24.5	1.1	0.8
	Oedek 4	57N74WS8	SWCA	8/30/2007	24-36	7.7	3.41	42.0	2.98	3.13	18.1	13.3	11.8	35	39	26	Loam		19.7	1.1	0.6
	Oedek 4	57N74WS8	SWCA	8/30/2007	36-48	7.7	1.47	35.7	1.41	1.49	7.4	4.9	3.5	59	22	19	Sandy Loam		14.6	0.3	0.2
	Oedek 4	57N74WS8	SWCA	8/30/2007	48-60	7.8	1.13	34.4	1.39	1.36	5.1	3.4	2.9	53	29	18	Sandy Loam		15.0	0.3	0.2
	Oedek 4	57N74WS8	SWCA	8/30/2007	60-72	7.8	0.85	29.0	1.33	1.30	3.4	2.3	2.3	71	16	13	Sandy Loam		11.3	0.2	0.2
11e	Oedek 5	57N74WS8	SWCA	8/30/2007	0-12	7.7	0.44	42.8	0.12	0.15	2.1	1.3	0.2	33	45	22	Loam	3.1	19.6	0.0	0.0
	Oedek 5	57N74WS8	SWCA	8/30/2007	12-24	8.0	0.43	38.3	1.35	1.27	1.6	1.2	1.6	35	41	24	Loam		19.2	0.3	0.2
	Oedek 5	57N74WS8	SWCA	8/30/2007	24-36	8.0	1.25	35.2	2.03	2.34	4.1	4.6	4.2	53	28	19	Sandy Loam		13.1	0.5	0.3
	Oedek 5	57N74WS8	SWCA	8/30/2007	36-48	7.9	1.25	43.7	1.74	2.80	4.4	4.8	3.7	<0.1	53	47	Silty Clay		17.5	0.7	0.5
	Oedek 5	57N74WS8	SWCA	8/30/2007	48-60	7.9	1.29	40.4	1.58	1.96	4.5	5.2	3.5	27	45	28	Clay Loam		16.5	0.5	0.3
	Oedek 5	57N74WS8	SWCA	8/30/2007	60-72	7.8	2.11	43.4	1.75	1.91	6.9	9.6	5.3	11	53	36	Silty Clay Loam		18.7	0.6	0.4
11f	Oedek 6	57N74WS8	SWCA	8/30/2007	0-12	7.5	0.39	49.0	0.12	0.12	2.3	1.3	0.2	11	54	35	Silty Clay Loam	3.9	32.2	0.1	0.0
	Oedek 6	57N74WS8	SWCA	8/30/2007	12-24	7.9	3.00	48.5	2.78	2.92	14.5	13.7	10.4	13	52	35	Silty Clay Loam		25.5	1.3	0.7
	Oedek 6	57N74WS8	SWCA	8/30/2007	24-36	8.3	6.01	43.2	6.27	8.27	17.9	47.3	47.2	31	43	26	Loam		19.2	3.8	1.6
	Oedek 6	57N74WS8	SWCA	8/30/2007	36-48	8.1	7.06	32.6	10.10	13.00	15.7	28.0	47.5	82	6	12	Loamy Sand		17.5	3.8	2.3
	Oedek 6	57N74WS8	SWCA	8/30/2007	48-60	8.1	6.09	29.8	7.10	6.30	18.2	29.3	34.6	67	17	16	Sandy Loam		15.2	2.0	1.0
	Oedek 6	57N74WS8	SWCA	8/30/2007	60-72	8.1	6.54	31.2	8.31	8.10	16.6	30.8	40.1	68	17	15	Sandy Loam		20.2	2.9	1.6
11g	Oedek 7	57N74WS8	SWCA	8/30/2007	0-12	7.8	0.55	36.9	0.57	0.37	3.4	2.0	0.9	43	36	21	Loam	2.9	13.8	0.1	0.1
	Oedek 7	57N74WS8	SWCA	8/30/2007	12-24	8.0	0.41	37.8	1.37	2.56	1.7	1.0	1.6	39	40	21	Loam		15.4	0.5	0.4
	Oedek 7	57N74WS8	SWCA	8/30/2007	24-36	8.0	1.57	41.5	2.51	3.29	5.6	6.3	6.1	18	53	29	Silty Clay Loam		25.0	1.1	0.8
	Oedek 7	57N74WS8	SWCA	8/30/2007	36-48	7.9	3.81	44.2	2.29	2.88	19.7	24.0	10.7	18	52	30	Silty Clay Loam		22.9	1.1	0.6
	Oedek 7	57N74WS8	SWCA	8/30/2007	48-60	7.9	2.49	33.2	2.34	2.20	10.7	12.6	8.0	48	34	18	Loam		12.9	0.8	0.3
	Oedek 7	57N74WS8	SWCA	8/30/2007	60-72	8.0	1.54	29.3	2.21	3.09	5.5	6.7	5.5	60	27	13	Sandy Loam		9.6	0.5	0.3
11h	Oedek 8	57N74WS8	SWCA	8/30/2007	0-12	7.1	0.56	46.5	0.33	0.07	2.6	2.5	0.5	29	45	26	Loam	5.1	26.8	0.0	0.0
	Oedek 8	57N74WS8	SWCA	8/30/2007	12-24	7.9	0.54	42.3	2.07	1.81	1.6	1.4	2.5	20	50	30	Clay Loam		23.7	0.5	0.4
	Oedek 8	57N74WS8	SWCA	8/30/2007	24-36	8.0	0.68	37.7	2.75	2.60	2.1	1.4	3.6	44	32	24	Loam		17.7	0.6	0.5
	Oedek 8	57N74WS8	SWCA	8/30/2007	36-48	8.0	1.23	36.8	2.10	2.25	4.5	4.4	4.4	41	34	25	Loam		14.9	0.5	0.3
	Oedek 8	57N74WS8	SWCA	8/30/2007	48-60	8.0	1.43	39.9	2.04	2.30	4.1	6.8	4.8	27	48	25	Loam		17.5	0.6	0.4
	Oedek 8	57N74WS8	SWCA	8/30/2007	60-72	8.1	1.36	38.3	1.94	2.16	3.7	6.6	4.4	<0.1	40	60	Clay		16.5	0.5	0.4
11i	Oedek 9	57N74WS8	SWCA	8/30/2007	0-12	8.3	0.37	48.1	0.32	0.15	1.7	1.4	0.4	11	52	37	Silty Clay Loam	4.7	29.5	0.1	0.0
	Oedek 9	57N74WS8	SWCA	8/30/2007	12-24	7.8	0.42	41.3	1.19	1.20	1.7	1.0	1.4	27	37	36	Clay Loam		32.1	0.4	0.4
	Oedek 9	57N74WS8	SWCA	8/30/2007	24-36	8.0	1.15	44.6	1.52	1.49	4.5	5.0	3.3	14	55	31	Silty Clay Loam		23.0	0.5	0.3
	Oedek 9	57N74WS8	SWCA	8/30/2007	36-48	8.0	1.65	41.7	1.96	2.00	4.4	8.8	5.0	17	51	32	Silty Clay Loam		22.0	0.7	0.5
	Oedek 9	57N74WS8	SWCA	8/30/2007	48-60	8.1	3.11	43.6	3.86	4.66	5.9	19.2	13.5	17	53	30	Silty Clay Loam		21.2	1.6	1.0
	Oedek 9	57N74WS8	SWCA	8/30/2007	60-72	8.1	5.52	56.4	5.73	6.75	7.1	40.4	27.9	3	57	40	Silty Clay		25.1	3.3	1.7
11j	Oedek 10	57N74WS8	SWCA	8/30/2007	0-12	7.3	0.48	46.0	0.38	0.25	2.3	1.8	0.6	25	39	36	Clay Loam	4.0	27.7	0.1	0.1
	Oedek 10	57N74WS8	SWCA	8/30/2007	12-24	7.9	0.48	42.1	0.72	0.46	1.9	1.8	1.0	27	37	36	Clay Loam		26.5	0.2	0.1
	Oedek 10	57N74WS8	SWCA	8/30/2007	24-36	8.1	0.58	54.3	0.97	0.76	1.7	2.4	1.4	11	37	52	Clay		35.8	0.4	0.3
	Oedek 10	57N74WS8	SWCA	8/30/2007	36-48	8.0	1.05	56.7	0.97	0.87	4.0	5.2	2.1	13	38	49	Clay		23.9	0.3	0.2
	Oedek 10	57N74WS8	SWCA	8/30/2007	48-60	7.6	2.45	49.2	0.68	0.87	23.3	10.5	2.4	23	33	44	Clay		24.7	0.3	0.2
	Oedek 10	57N74WS8	SWCA	8/30/2007	60-72	7.6	2.56	46.0	0.64	1.13	21.4	9.6	2.1	26	32	42	Clay		23.7	0.4	0.3
11k	Oedek 11	57N74WS8	SWCA	8/30/2007	0-12	7.9	0.45	40.5	0.20	0.13	2.3	1.4	0.3	28	44	28	Clay Loam	2.6	20.5	0.0	0.0
	Oedek 11	57N74WS8	SWCA	8/30/2007	12-24	8.0	0.32	40.0	0.83	0.72	1.4	0.8	0.9	21	52	27	Clay Loam		27.0	0.2	0.2
	Oedek 11	57N74WS8	SWCA	8/30/2007	24-36	8.3	0.53	45.4	1.39	1.79	1.5	1.7	1.8	11	56	33	Silty Clay Loam		22.4	0.5	0.4
	Oedek 11	57N74WS8	SWCA	8/30/2007	36-48	8.0	1.43	44.2	0.84	1.26	4.6	3.1	2.2	15	57	28	Silty Clay Loam		20.0	0.4	0.3
	Oedek 11	57N74WS8	SWCA	8/30/2007	48-60	7.8	2.89	42.4	0.55	1.01	21.4	15.4	2.4	28	46	26	Loam		16.5	0.3	0.2
	Oedek 11	57N74WS8	SWCA	8/30/2007	60-72	7.8	2.54	33.6	0.46	1.09	20.6	10.9	1.8	61	23	16	Sandy Loam		9.7	0.2	0.1
11l	Oedek 12	57N74WS8	SWCA	8/30/2007	0-12	7.3	0.57	48.8	0.33	0.29	1.8	1.2	0.4	11	45	44	Silty Clay	5.4	35.7	0.1	0.1
	Oedek 12	57N74WS8	SWCA	8/30/2007	12-24	7.7	2.58	48.0	1.10	1.34	18.6	10.1	4.2	19	42	39	Silty Clay Loam		27.6	0.6	0.4
	Oedek 12	57N74WS8	SWCA	8/30/2007	24-36	7.8	1.68	31.1	1.54	1.77	8.7	5.7	4.1	64	19	17	Sandy Loam		13.7	0.4	0.2
	Oedek 12	57N74WS8	SWCA	8/30/2007	36-48	7.9	0.82	31.4	1.35	1.49	3.3	2.3	2.5	63	19	18	Sandy Loam		15.1	0.3	0.2
	Oedek 12	57N74WS8	SWCA	8/30/2007	48-60	7.9	0.64	30.4	1.41	1.71	2.3	1.6	2.0	61	22	17	Sandy Loam		13.8	0.3	0.2
	Oedek 12	57N74WS8	SWCA	8/30/2007	60-72	7.9	0.65	33.7	1.60	1.48	2.5	1.6	2.2	51	28	21	Loam		17.0	0.3	0.3

Notes:
1. Soil samples were collected by BKS Environmental Associates, Inc. (BKS), SWCA Environmental Consultants (SWCA) and KC Harvey, Inc (KCH).
Abbreviations: TRS = Township, Range, Section; S.U. = Standard units; dS/m = decisiemens per meter; % = percent; SAR = Sodium adsorption ratio; ESP = Exchangeable sodium percentage; Ca = Calcium; Mg = Magnesium; Na = Sodium; CEC = Cation exchange capacity; EC = Electrical conductivity; OM = Organic matter; Na-Ext = Extractable sodium; Exch Na = Exchangeable sodium; meq/L = milliequivalents per liter; meq/100g = milliequivalents per 100 grams of soil.

Elevation	Area ac	Capacity ac-ft	Description
3,639	0	0	
3,640	1.32	0.66	
3,641	2.79	2.71	
3,642	4.35	6.28	
3,643	5.61	11.25	
3,644	7.38	17.75	
3,645	12.25	27.56	
3,646	15.48	41.42	12" cmp
3,647	17.72	58.02	
3,648	20.6	77.18	
3,649	23.14	99.05	Spillway

Notes

1 Headgate capacity calculations performed by Lowham Engineering, LLC.

Bitter Creek Drainage area = 82.39 sq. mi.		
Average annual precipitation = 16 inches.		
Streamflow Characteristic	Streamflow cfs	Volume[2] ac-ft
P1.5 [3]	152	10.8
P2	243	16.3
P5	602	36.1
P10	963	54.5
P25	1560	83.4
P50	2110	108.6
P100	2766	137.8
Qa [4]	2.761	

Notes:

1. Hydraulic assessments calculations performed by Lowham Engineering, LLC.
2. Volumes computed from Craig and Rankl (1978), for areas less than 11 mi^2.
3. P = annual peak flow in cubic feet per second. Number designates the reoccurrence interval in years.
4. Qa = annual peak flow in cubic feet per second.

Table 4. Estimated produced and Bitter Creek water qualities and associated mixing sensetivity analysis

Column	1	2	3	4	5	6	7	8	9	10	11	12	13
Parameter	Produced Water 1[1]		Produced Water 2[2]		Bitter Creek Water 1[3]		Bitter Creek Water 2[4]		BC1 (93%) PW1 (7%)[5]		BC2 (93%) PW1 (7%)[6]		BC2 (93%) P
	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L
HCO3	1060	17.4	2421	39.7	642	10.5	85	1.4	675	11.1	153	2.5	290
Ca	16	0.8	37	1.9	263	13.2	42	2.1	247	12.3	40	2.0	42
Cl	26	0.7	59	1.7	39	1.1	1	0.0	38	1.1	3	0.1	6
K	6	0.2	14	0.4	25	0.6	4	0.1	24	0.6	0.4	0.0	1
Mg	8	0.7	18	1.5	536	44.7	70	5.8	496	41.3	65	5.4	66
Na	398	17.3	909	39.5	800	34.8	127	5.5	777	33.8	121	5.3	173
SO4	3	0.1	7	0.1	3800	79.2	605	12.6	3554	74.0	512	10.7	512
SAR[8]	--	20.2	--	30.5	--	6.5	--	2.6	--	6.5	--	2.7	--
EC	1.6	--	3.7	--	8.2	--	1.3	--	7.7	--	1.3	--	1.5
Cations	--	18.9	--	43.2	--	93.2	--	13.6	--	88.0	--	12.7	--
Anions	--	18.2	--	41.5	--	90.8	--	14.0	--	86.2	--	13.3	--

Notes

1 Produced Water 1 is the expected produced water quality that will be delivered to the proposed reservoirs within HomeStead Draw II POD.

2 Produced Water 2 is simulated water chemistry of produced water that could enter the reservoirs based on the Tier II assessment.

3 Bitter Creek Water 1 is the water chemistry of Bitter Creek water collected by Stormcat Energy on 5/22/07 WQMS data was not used due to the lack analyses performed. To calibrate the geochemical model to an EC of 8.2 dS/m the sulfate concentration had to be reduced by 1000 mg/L and Sodium was reduced by 550 mg/L.

4 Bitter Creek water 2 is simulated water chemistry that would have an EC of 1.3 dS/m.

5 Projected water quality of water that could be irrigated to the Oedekoven fields assuming 93 % Bitter Creek Water 1 and 7% Produced Water 1.

6 Projected water quality of water that could be irrigated to the Oedekoven fields assuming 93 % Bitter Creek Water 2 and 7 % Produced Water 1.

7 Projected water quality of water that could be irrigated to the Oedekoven fields assuming 93 % Bitter Creek Water 2 and 7 % Produced Water 2.

8 SAR values are unitless.

Abbreviations: HCO3 = Bicarbonate; Ca = Calcium; Cl = Chloride; K = Pottasium; Mg = Magnesium; Na= Sodium; SO4 = Sulfate; SAR = Sodium adsorption ratio; EC = Electrical conductivity; mg/L = miligram per liter, meq/L = milliequivalent per liter.

Table 5. Soil physicochemical dataset used to develop Tier 2 historic background water quality of Bitter Creek.

Dataset #	Original Name	TRS	Sampled By[1]	Collection Date	Sample Depth	pH	EC	Percent Sat	SAR	ESP	Ca	Mg	Na	Sand	Silt	Clay	Texture	OM	CEC	Na-Ext	Ex
					Inches	S.U.	dS/m	%	Unitless	%		meq/L			%		Unitless	%		meq/100g	
3	1A	57N73WS36	SWCA	6/11/2007	0-12	7.0	3.05	72.8	0.73	1.70	23.3	15.2	3.2	14	52	34	Silty Clay Loam	7.3	34.9	0.8	
	1B	57N73WS36	SWCA	6/11/2007	12-24	7.5	5.63	49.4	4.10	5.40	27.4	30.1	21.9	38	34	28	Clay Loam		23.6	2.4	
	1C	57N73WS36	SWCA	6/11/2007	24-36	7.5	4.78	50.6	3.50	5.90	25.8	23.4	17.5	30	42	28	Clay Loam		22.6	2.2	
	1D	57N73WS36	SWCA	6/11/2007	36-48	7.4	5.30	37.8	3.80	7.00	27.9	27.2	20.2	49	29	22	Loam		20.1	2.2	
6	Crockett Field Sub 2	57N74WS26	KCH	12/6/2007	0-12	7.9	7.54	65.7	12.00	13.00	18.9	30.0	57.3	6	57	37	Silty Clay Loam	2.2	30.7	7.8	
	Crockett Field Sub 2	57N74WS26	KCH	12/6/2007	12-24	8.2	11.90	63.0	17.00	18.00	18.2	40.9	94.6	8	60	32	Silty Clay Loam	1.1	25.8	10.6	
	Crockett Field Sub 2	57N74WS26	KCH	12/6/2007	24-36	8.2	10.70	60.7	16.00	16.00	18.7	43.1	88.4	12	58	30	Silty Clay Loam	1.2	26.5	10.1	
	Crockett Field Sub 2	57N74WS26	KCH	12/6/2007	36-48	8.0	7.60	63.0	12.00	14.00	18.5	31.3	58.6	12	56	32	Silty Clay Loam	1.3	25.0	7.2	
	Crockett Field Sub 2	57N74WS26	KCH	12/6/2007	48-60	8.0	8.30	59.5	12.00	13.00	19.0	30.6	60.9	22	49	29	Clay Loam	1.2	25.2	6.9	
	Crockett Field Sub 2	57N74WS26	KCH	12/6/2007	60-72	8.0	6.11	58.8	10.00	16.00	15.8	24.5	45.4	13	53	34	Silty Clay Loam	0.9	20.8	6.0	
7	Crockett Field 4 & 5	57N74WS26	KCH	12/6/2007	0-12	7.4	1.35	65.0	1.80	2.90	4.6	4.3	3.8	10	52	38	Silty Clay Loam	3.6	29.1	1.1	
	Crockett Field 4 & 5	57N74WS26	KCH	12/6/2007	12-24	7.8	6.38	55.8	9.00	14.00	18.6	26.0	42.5	12	56	32	Silty Clay Loam	1.9	22.1	5.4	
	Crockett Field 4 & 5	57N74WS26	KCH	12/6/2007	24-36	8.3	8.92	59.3	16.00	18.00	15.1	39.0	82.7	18	54	28	Silty Clay Loam	1.3	27.8	10.0	
	Crockett Field 4 & 5	57N74WS26	KCH	12/6/2007	36-48	8.3	8.67	61.0	16.00	21.00	15.1	34.0	77.0	16	56	28	Silty Clay Loam	1.4	22.8	9.6	
	Crockett Field 4 & 5	57N74WS26	KCH	12/6/2007	48-60	8.1	7.82	54.3	13.00	15.00	17.7	32.4	65.4	22	52	26	Silt Loam	1.2	22.4	6.9	
	Crockett Field 4 & 5	57N74WS26	KCH	12/6/2007	60-72	8.1	7.51	52.8	13.00	12.00	18.6	31.4	63.9	26	49	25	Loam	1.1	23.7	6.3	
8	3A (Site4)	57N74WS22	SWCA	7/25/2007	0-12	8.6	11.60	73.7	14.00	13.00	21.1	46.7	83.3	11	52	37	Silty Clay Loam	4.7	39.0	11.3	
	3B (Site4)	57N74WS22	SWCA	7/25/2007	12-24	7.9	10.50	90.5	14.00	20.00	19.7	43.7	78.7	6	54	40	Silty Clay		31.5	13.6	
	3C (Site4)	57N74WS22	SWCA	7/25/2007	24-36	7.8	11.00	90.0	14.00	16.00	22.9	48.5	84.1	6	48	46	Silty Clay		27.4	12.0	
	3D (Site4)	57N74WS22	SWCA	7/25/2007	36-48	7.8	8.66	85.2	9.70	18.00	20.8	32.2	49.6	6	48	46	Silty Clay		22.0	8.2	
9	2A (Site3)	57N74WS22	SWCA	7/25/2007	0-12	8.1	2.73	68.4	13.00	12.00	3.3	3.7	23.7	4	57	39	Silty Clay Loam	3.9	35.5	5.9	
	2B (Site3)	57N74WS22	SWCA	7/25/2007	12-24	8.0	3.30	43.5	5.40	9.10	14.8	8.9	18.7	34	46	20	Loam		22.5	2.9	
	2C (Site3)	57N74WS22	SWCA	7/25/2007	24-36	8.2	2.00	46.7	7.00	7.70	4.7	3.4	13.9	27	51	22	Silty Loam		25.3	2.6	
	2D (Site3)	57N74WS22	SWCA	7/25/2007	36-48	8.1	2.38	62.3	6.30	8.80	7.1	5.3	15.6	10	57	33	Silty Clay Loam		24.8	3.1	
10	1A (Sites 1&2)	57N74WS22	SWCA	7/25/2007	0-12	7.8	7.45	64.7	8.10	8.20	22.9	29.9	41.8	11	51	38	Silty Clay Loam	3.2	32.9	5.4	
	1B (Sites 1&2)	57N74WS22	SWCA	7/25/2007	12-24	7.8	5.74	75.0	8.20	8.00	13.2	17.6	32.2	16	45	39	Silty Clay Loam		40.0	5.7	
	1C (Sites 1&2)	57N74WS22	SWCA	7/25/2007	24-36	7.9	7.16	81.2	7.40	13.00	20.8	31.2	37.8	6	44	50	Silty Clay		25.5	6.4	
	1D (Sites 1&2)	57N74WS22	SWCA	7/25/2007	36-48	7.8	8.01	77.0	7.70	10.00	20.8	35.6	40.8	13	45	42	Silty Clay		20.0	6.1	
11f	Odek 6	57N74WS8	SWCA	8/30/2007	0-12	7.5	0.39	49.0	0.12	0.12	2.3	1.3	0.2	11	54	35	Silty Clay Loam	3.9	32.2	0.1	
	Odek 6	57N74WS8	SWCA	8/30/2007	12-24	7.9	3.00	48.5	2.78	2.92	14.5	13.7	10.4	13	52	35	Silty Clay Loam		25.5	1.3	
	Odek 6	57N74WS8	SWCA	8/30/2007	24-36	8.3	8.01	43.2	8.27	8.27	17.9	47.3	47.2	31	43	26	Loam		19.2	3.6	
	Odek 6	57N74WS8	SWCA	8/30/2007	36-48	8.1	7.06	32.6	10.10	13.00	15.7	28.0	47.0	82	6	12	Loamy Sand		17.5	3.8	
	Odek 6	57N74WS8	SWCA	8/30/2007	48-60	8.1	6.09	29.6	7.10	6.30	18.2	29.3	34.6	67	17	16	Sandy Loam		15.2	2.0	
	Odek 6	57N74WS8	SWCA	8/30/2007	60-72	8.1	6.54	31.2	8.31	8.10	16.6	30.0	40.1	68	17	15	Sandy Loam		20.2	2.9	

Notes

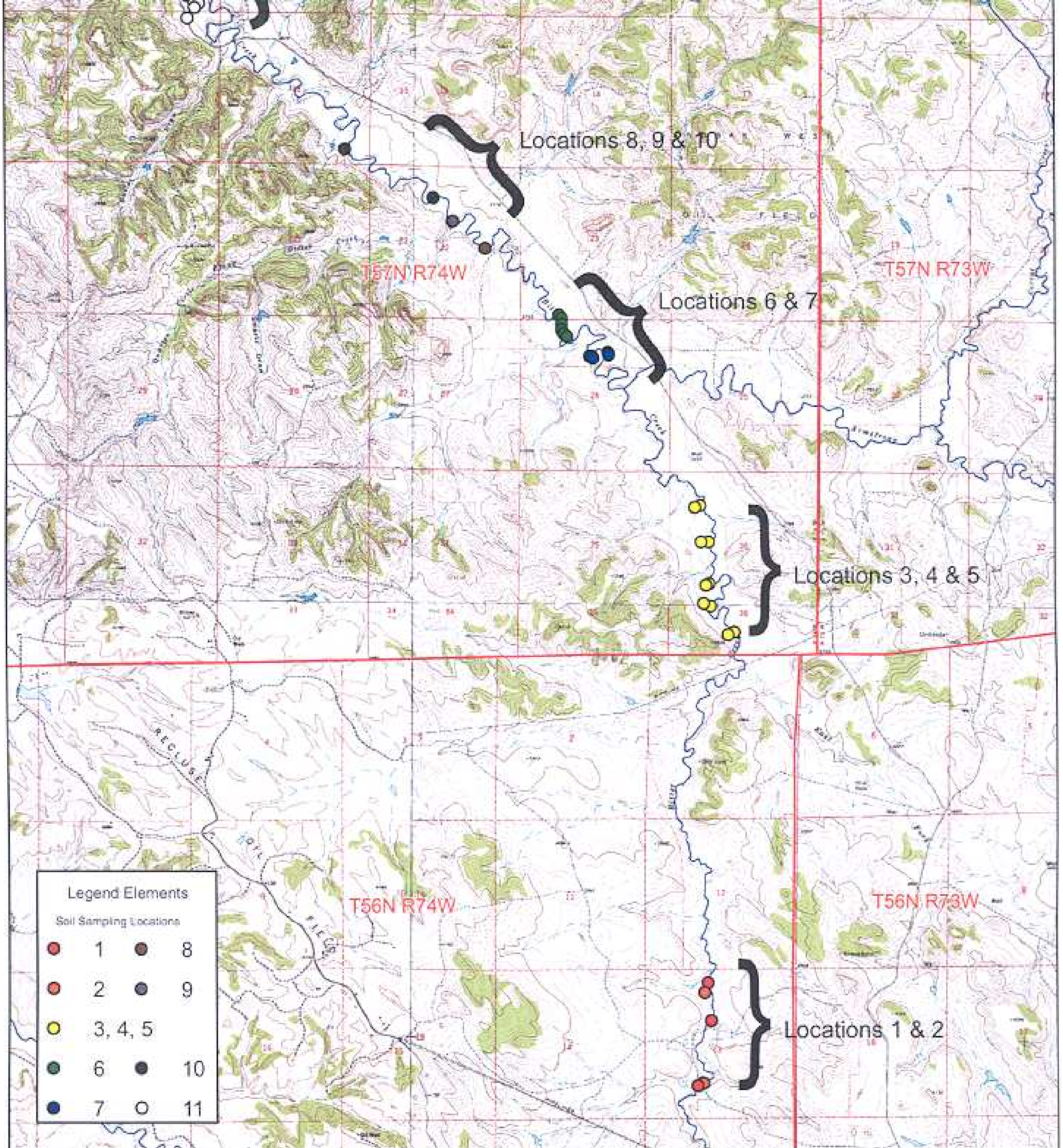
1. Soil samples were colected by BKS Environmental Associates, Inc. (BKS), SWCA Environmental Consultants (SWCA) and KC Harvey, Inc (KCH).

Abbreviations: TRS = Township, Range, Section; S.U. = Standard units; dS/m = deciseimens per meter; % = percent; SAR = Sodium adsorption ratio; ESP = Exchangeable sodium percentage; Ca = Calcium; Mg = Magnesium; Na = Sodium; CEC = Cation exchange capacity; EC = Electrical conductivity; OM = Organic matter; Na-Ext = Extractable sodium; Exch Na = Exchangeable sodium; meq/L = milliequivalents per liter; meq/100g = milliequivalents per 100 grams of soil.

Descriptive Statistics[1]	(dS/m)
Normally Distributed	Yes
Presence of Outliers	No
Mean	6.6
Standard Deviation	3.0
Standard Error	0.5
Lower Bound 95 % C.I. of Mean	5.5
Median	7.1
Recommended End-of-pipe Effluent Limit = 3.7[2]	

Notes

1. With the exception of the recommended effluent limit, all descriptive statistics derived using SPSS statistical software (2001).
2 Recommended end-of-pipe effluent limit is based on methods used by the WDEQ on other permits within the Powder River Basin.



KC HARVEY
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0 1,200 2,400 4,800 Feet

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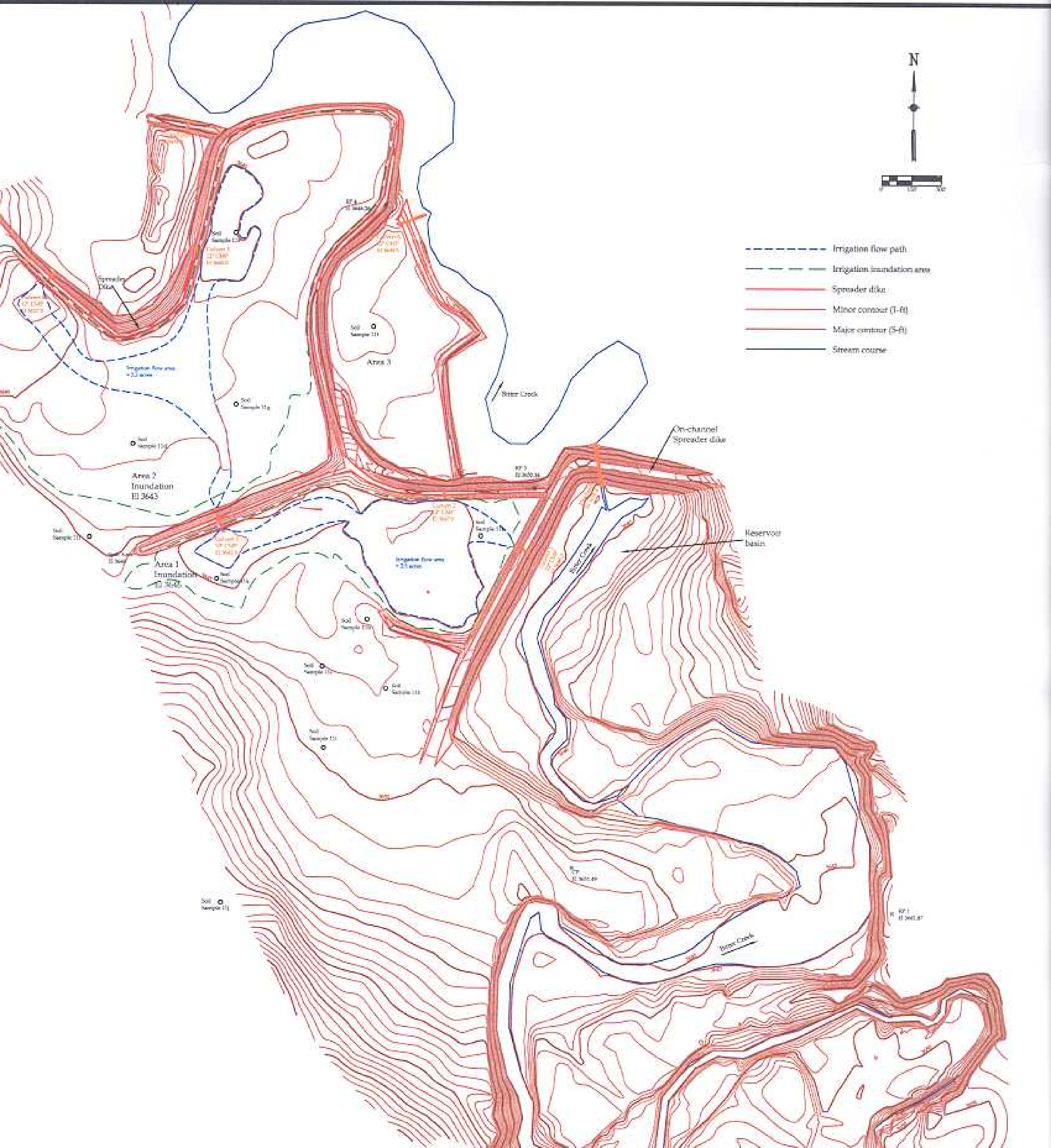
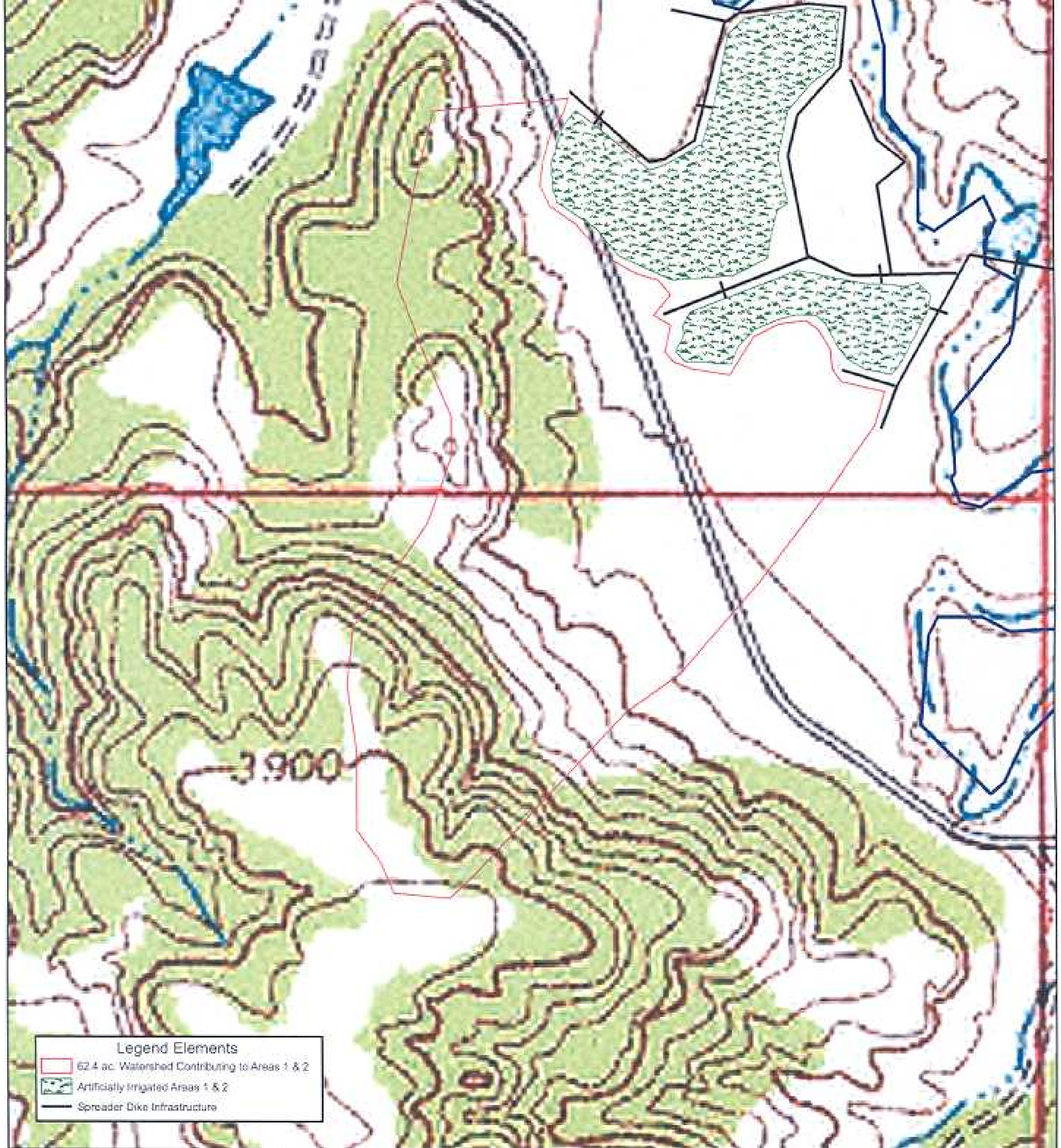
Figure 1. Soil sampling locations along the Bitter Creek Drainage.

Project: Bitter Creek Sec. 20	Date: 1/30/08	Revision: Ver. 2


N
Irrigation flow path
Irrigation inundation area
Spreader dike
Minor contour (1-ft)
Major contour (5-ft)
Stream course
Briar Creek
On-channel Spreader dike
Reservoir basin
Area 3
Area 2 Inundation El 3643
Area 1 Inundation El 3645
Spreader Dike
Irrigation flow area
Briar Creek



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0 125 250 500 Feet

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Figure 3. Watershed area contributing runoff directly to the Oedekoven flood irrigation areas 1 & 2.

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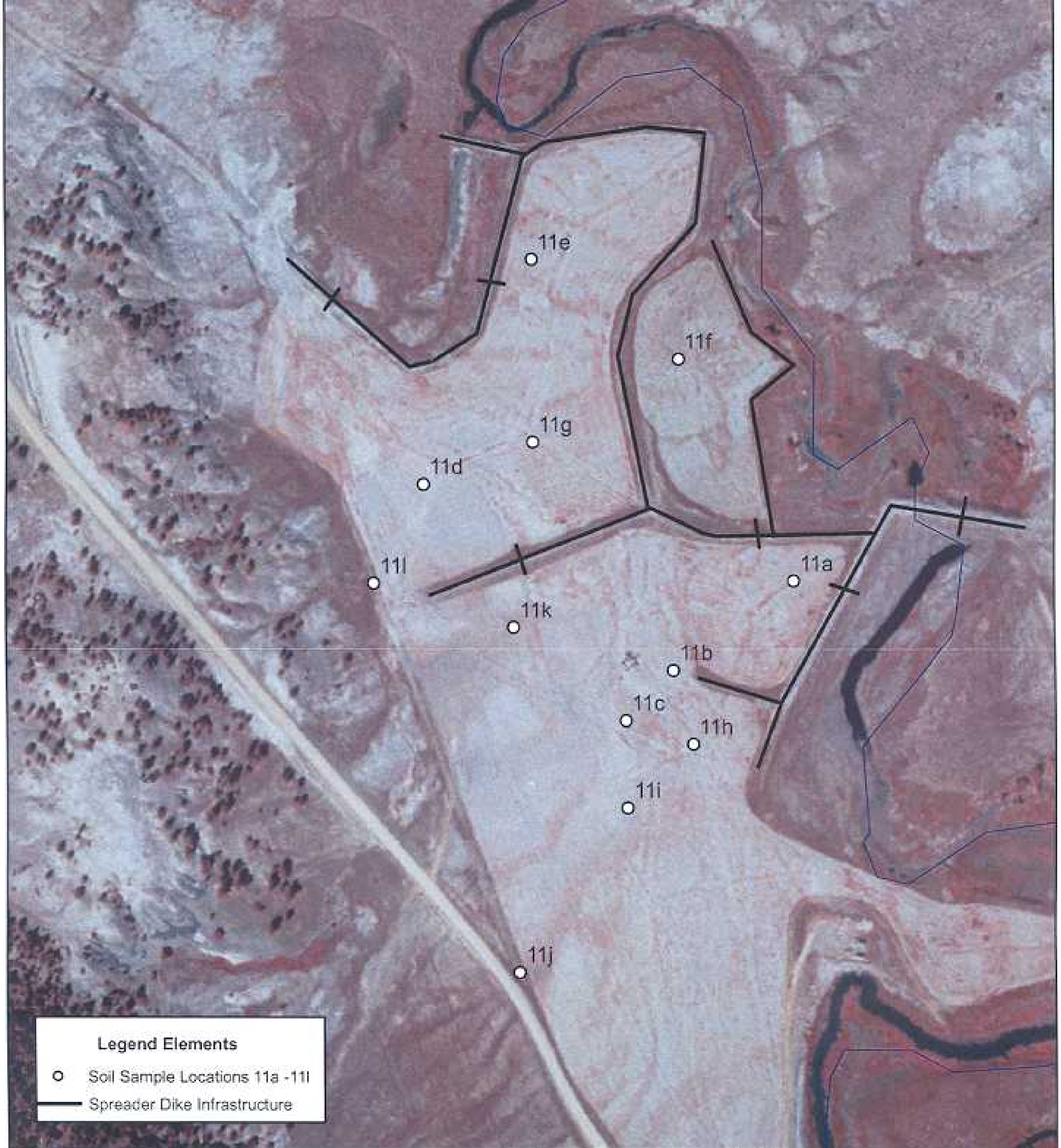

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0 80 160 320 Feet

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Figure 4. 2002 color infrared aerial image of the Oedekoven flood irrigation areas.

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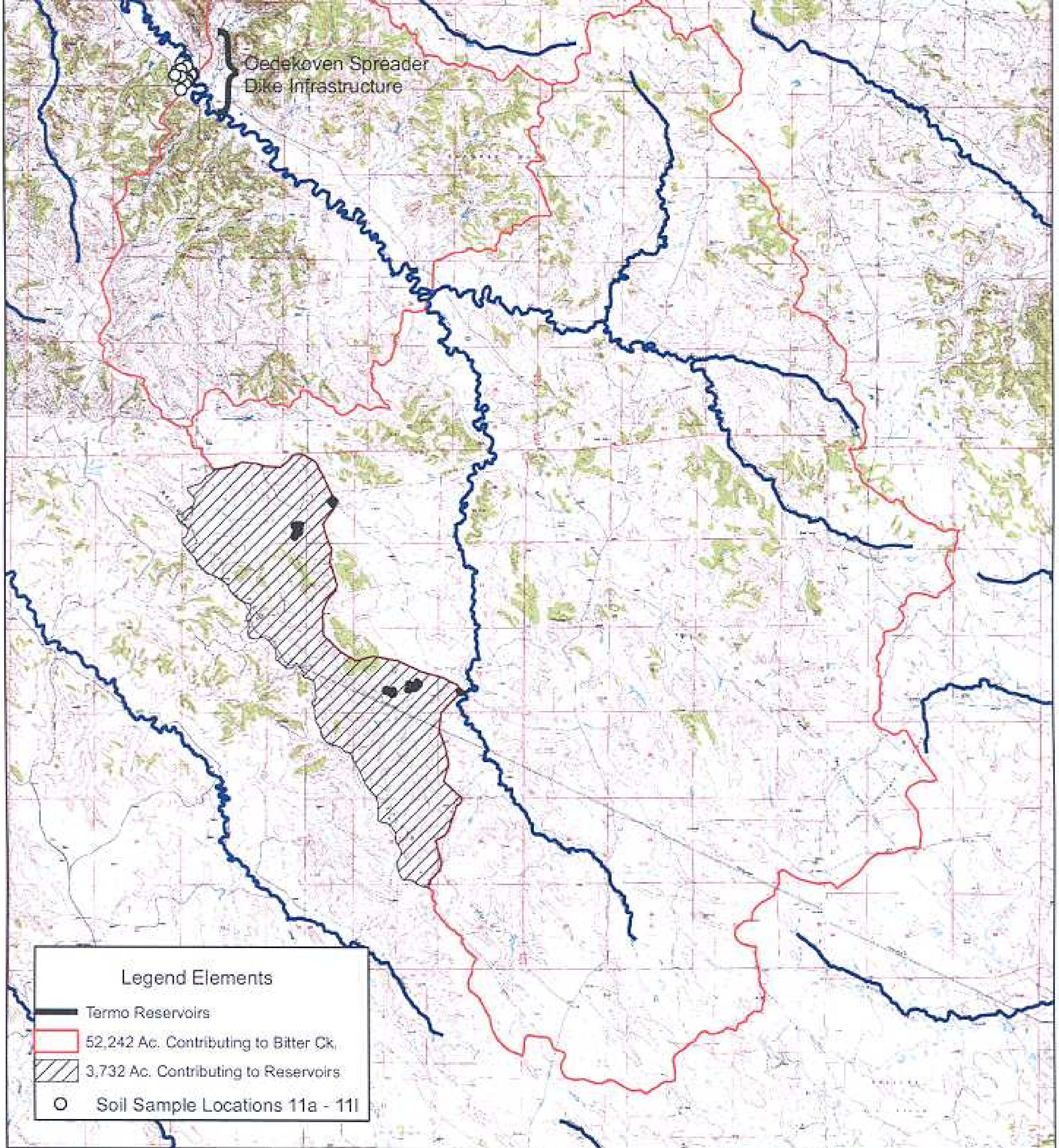

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0 2,500 5,000 10,000 Feet

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Figure 5. Watershed of the Bitter Creek drainage above the Oedekoven flood irrigation areas.

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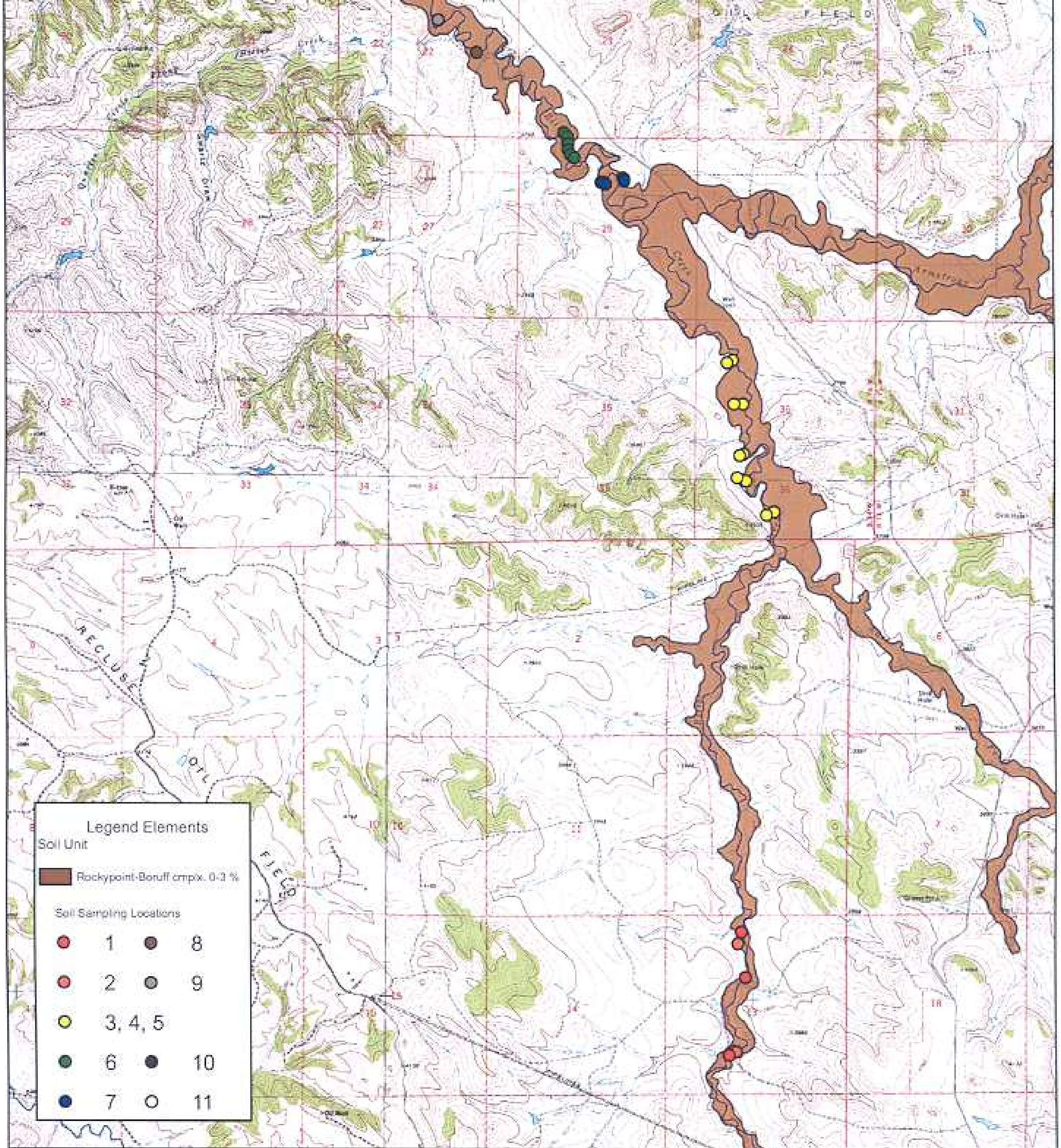

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0 1,050 2,100 4,200 Feet

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Figure 6. NRCS soil mapping units associated with soil sampling locations 1-10.

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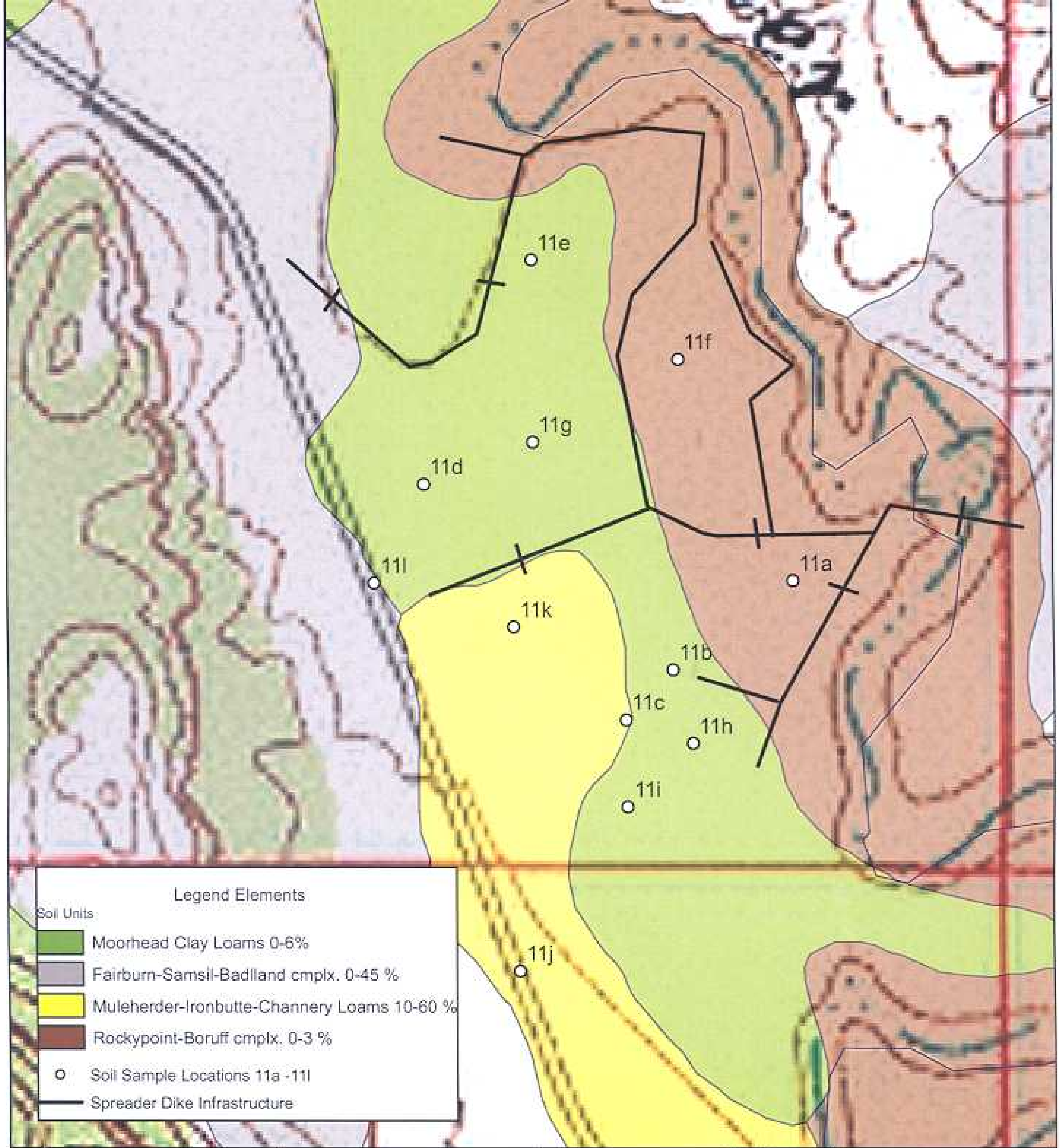

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0 80 160 320 Feet

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Figure 7. NRCS soil mapping units associated with the Oedekoven flood irrigation areas.

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APPENDIX A: OFFICIAL SOIL SERIES DESCRIPTIONS

ROCKYPOINT SERIES

The Rockypoint series consists of very deep, well drained soils formed in recent alluvium derived from mixed sedimentary sources. Rockypoint soils are on flood plains and low terraces. Slopes are 0 to 6 percent. The mean annual precipitation is about 15 inches, and the mean annual air temperature is about 46 degrees F.

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

TYPICAL PEDON: Rockypoint loam -- on a southwest facing flood plain slope of about 1 percent, utilized as rangeland. (Colors are for dry soil unless otherwise stated)

A--0 to 3 inches; grayish brown (10YR 5/2) loam, brown (10YR 4/3) moist; weak fine platy structure; slightly hard, friable, sticky and slightly plastic; common fine and very fine, few coarse and medium roots; slightly effervescent, calcium carbonate disseminated; slightly alkaline (pH 7.6); clear smooth boundary. (1 to 6 inches thick)

C1--3 to 30 inches; pale brown (10YR 6/3) clay loam, stratified with thin layers of sandy loam, loam, silt loam, and silty clay loam, brown (10YR 5/3) moist; massive; hard, friable, sticky and plastic; common fine and very fine, few coarse and medium roots to about 25 inches, few fine and very fine roots below; slightly effervescent, calcium carbonate disseminated; moderately alkaline (pH 8.0); clear smooth boundary.

C2--30 to 60 inches; pale brown (10YR 6/3) loam, stratified with thin layers of loamy sand, sandy loam, very fine sandy loam, and clay loam, brown (10YR 5/3) moist; massive; hard, friable, slightly sticky and plastic; few fine and very fine roots; slightly effervescent, calcium carbonate disseminated; moderately alkaline (pH 8.2).

TYPE LOCATION: Campbell County, Wyoming; about 1,160 feet west and 2,350 feet south of the northeast corner of section 2, T. 51 N., R. 75 W. 44 degrees 25 minutes 36 seconds north latitude and 105 degrees 50 minutes 13 seconds west longitude.

RANGE IN CHARACTERISTICS: The organic carbon content ranges from 1 to 2 percent in the A horizon and from .5 to 1.5 percent in the C horizon and decreases irregularly with depth. Depth to effervescent horizons is 0 to 10 inches. Exchangeable sodium is typically less than 5 percent but ranges from 0 to 10 percent. The moisture control section is usually moist in some or all parts in March through June. The average annual soil temperature is 47 to 50 degrees F. Rock fragments range from 0 to 10 percent.

The A horizon has hue of 10YR or 2.5Y, value of 4 to 6 dry and 3 to 5 moist, and chroma of 2 to 4. Electrical conductivity ranges from 0 to 4 millimhos per centimeter. It is slightly alkaline or moderately alkaline. Textures are variable. Some pedons have an AC horizon.

Electrical conductivity is commonly 0 to 4 millimhos per centimeter, but may range to 12 millimhos in some pedons. It is slightly alkaline through strongly alkaline.

COMPETING SERIES: These are the Aparejo, Haverson, Hysham and Ramper series. It is assumed the Hickman series is competing pending an update of the classification. Aparejo, Hickman and Ramper soils are usually driest in May and June. Haverson soils are moist in some part in July through September. Hysham soils are very strongly alkaline.

GEOGRAPHIC SETTING: Rockypoint soils are on flood plains and low terraces. They formed in stratified recent alluvium derived from mixed sedimentary sources. Slopes are 0 to 6 percent. Elevations are 3,500 to 5,500 feet. The mean annual precipitation ranges from 15 to 17 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 Boruff, Deekay, Iwait, Oldwolf, Fairburn and Ucross soils. Boruff soils are poorly and somewhat poorly drained. Deekay and Oldwolf soils have argillic horizons. Iwait soils have a regular decrease in organic matter and have horizons of uniform textures below the A horizon. Fairburn soils are shallow. Ucross soils are moderately deep. The Boruff soils occur in similar positions. The Deekay, Iwait, Oldwolf, Fairburn and Ucross soils occur on uplands.

DRAINAGE AND PERMEABILITY: Well drained; slow runoff; moderate 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.

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.

DISTRIBUTION AND EXTENT: Rockypoint soils occur in the Powder River basin of north-central and northeastern Wyoming. The series is of limited extent.

MLRA OFFICE RESPONSIBLE: Bismarck, North Dakota

SERIES ESTABLISHED: Campbell County, Wyoming, Southern Part; 1995.

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

Ochric epipedon - 0 to 3 inches (A)

SIR- WY1376

LRR- G

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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

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.

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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MOORHEAD SERIES

The Moorhead series consists of very deep, well drained soils formed in alluvium derived primarily from shale. Moorhead soils are on fan remnants, alluvial fans, plateaus, terraces, valley fill positions, ridges and hills. Slopes are 0 to 15 percent. The mean annual precipitation is about 15 inches, and the mean annual air temperature is about 46 degrees F.

TAXONOMIC CLASS: Fine, smectitic, mesic Torrertic Haplustalfs

TYPICAL PEDON: Moorhead clay loam -- on an north facing slope of 1 percent, utilized as rangeland. (Colors are for dry soil unless otherwise stated)

A--0 to 4 inches; brown (10YR 5/3) clay loam, brown (10YR 4/3) moist; weak medium subangular blocky structure parting to weak fine granular; slightly hard, friable, moderately sticky and moderately plastic; many very fine and fine roots throughout; many fine vescular pores throughout; noneffervescent; neutral (pH 7.3); clear smooth boundary. (1 to 8 inches thick)

Bt--4 to 18 inches; brown (10YR 4/3) clay, dark brown (10YR 3/3) moist; strong medium and coarse prismatic structure parting to moderate fine and medium angular blocky; very hard, firm, very sticky and very plastic; common fine roots and few medium roots throughout; many fine irregular pores throughout; many distinct continuous very dark grayish brown (10YR 3/2) clay films on faces of peds; noneffervescent; slightly alkaline (pH 7.6); clear wavy boundary. (7 to 24 inches thick)

Btk--18 to 24 inches; brown (10YR 5/3) clay, brown (10YR 4/3) moist; strong medium and coarse prismatic structure parting to moderate fine and medium angular blocky; very hard, firm, very sticky and very plastic; common very fine and fine roots throughout; many fine irregular pores throughout; common distinct discontinuous dark brown (10YR 3/3) clay films on faces of peds; common fine irregular light gray (10YR 7/2) carbonate threads throughout; strongly effervescent; moderately alkaline (pH 8.0); gradual wavy boundary. (6 to 13 inches thick)

Bk1--24 to 32 inches; light olive brown (2.5Y 5/3) clay, olive brown (2.5Y 4/3) moist; strong medium and coarse prismatic structure parting to moderate fine and medium angular blocky; hard, firm, very sticky and very plastic; common very fine and fine roots throughout; common fine irregular pores throughout; common fine irregular light gray (10YR 7/2) carbonate threads throughout; violently effervescent; moderately alkaline (pH 8.2); gradual wavy boundary.

Bk2--32 to 60 inches; light yellowish brown (2.5Y 6/3) clay loam, olive brown (2.5Y 4/3) moist; moderate fine and medium angular blocky; hard, friable, moderately sticky and moderately plastic; common fine irregular pores throughout; common fine irregular light gray (10YR 7/2) carbonate threads throughout; strongly effervescent; moderately alkaline (pH 8.4).

TYPE LOCATION: Campbell County, Wyoming; about 2450 feet east and 1450 feet north of the

RANGE IN CHARACTERISTICS: Depth to the base of the argillic horizon is 21 to 35 inches. Depth to accumulations of calcium carbonate is typically 13 to 20 inches, but ranges to 34 inches in some pedons. It has 0 to 10 percent rock fragments throughout. Electrical conductivity is 0 to 4 millimhos per centimeter. The moisture control section is usually moist in some or all parts in March through June. The average annual soil temperature is 47 to 50 degrees F.

The A horizon has hue of 10YR or 2.5Y, value of 5 or 6 dry and 3 to 5 moist, and chroma of 2 or 3. It is clay loam, silty clay loam, loam or silt loam. It is neutral or slightly alkaline. Some pedons have an AB horizon up to 5 inches thick.

The Bt horizon has hue of 7,5YR, 10YR or 2.5Y, value of 5 or 6 dry and 3 to 5 moist, and chroma of 2 to 4. Texture is clay loam, silty clay or clay. It has 35 to 50 percent clay and 10 to 30 percent fine and coarser sand. It is neutral or slightly alkaline.

The Btk horizon has hue of 10YR or 2.5Y, value of 5 to 7 dry and 4 or 5 moist, and chroma of 2 to 4. Texture is clay loam, silty clay or clay with 35 to 50 percent clay. It has 4 to 12 percent calcium carbonate equivalent. It is moderately alkaline or strongly alkaline.

The Bk horizon has hue of 10YR or 2.5Y, value of 5 to 7 dry and 4 or 5 moist, and chroma of 2 to 4. Texture is clay loam, clay, silty clay loam or loam. It has 4 to 15 percent calcium carbonate equivalent. Exchangeable sodium is typically less than 5 percent but ranges from 0 to 10 percent. It is moderately alkaline or strongly alkaline.

COMPETING SERIES: These are the Demar, Horselake, Teeque and Thurlow series. Demar soils are more acid and have a Bz horizon. Horselake soils are moderately deep. Teeque soils are dry during the period of April through June. Thurlow soils do not have a Btk horizon and are cooler.

GEOGRAPHIC SETTING: Moorhead soils are on fan remnants, alluvial fans, plateaus, terraces, valley fill positions, hills and ridges. They formed in alluvium derived primarily from shale. Slopes are 0 to 15 percent. Elevations are 3,500 to 5,000 feet. The mean annual precipitation ranges from 15 to 17 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 Cromack, Deekay, Echeta, Jaywest, Leiter, Oldwolf and Spottedhorse soils. Deekay and Oldwolf soils are fine-loamy. Echeta and Cromack soils have cambic horizons and are calcareous throughout. Jaywest and Spottedhorse soils have an absolute increase of more than 15 percent clay within a vertical distance of one inch at the upper boundary of the Bt horizon. Lieter soils are moderately deep. Deekay, Echeta, and Jaywest soils are on similar positions. Lieter, Oldwolf, Cromack, and Spottedhorse soils are on shoulders and summits on hills and ridges.

DRAINAGE AND PERMEABILITY: Well drained; medium to very high runoff, depending on slope; slow permeability.

USE AND VEGETATION: These soils are utilized as rangeland, hayland and pasture, irrigated and nonirrigated cropland, and wildlife habitat. The native vegetation is mainly western wheatgrass, green needlegrass, blue grama and big sagebrush. Winter wheat, oats, barley and alfalfa are the principle and northeastern Wyoming. The series is of limited extent.

MLRA OFFICE RESPONSIBLE: Bismarck, North Dakota

SERIES ESTABLISHED: Campbell County, Wyoming, Southern Part; 1995.

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

Ochric epipedon - 0 to 4 inches (A horizon)

Argillic horizon - 4 to 24 inches (Bt, Btk)

SIR- WY1378

LRR- G

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FAIRBURN SERIES

The Fairburn series consists of shallow, somewhat excessively drained and well drained soils on gently sloping to very steep upland hills and ridges. They formed in residuum weathered from mudstone, very fine-grained sandstone, siltstone or shale. Permeability is moderate or moderately slow. Slopes range from 3 to 60 percent. Mean annual precipitation is about 15 inches, and mean annual air temperature is about 47 degrees F.

TAXONOMIC CLASS: Loamy, mixed, superactive, calcareous, mesic, shallow Aridic Ustorthents

TYPICAL PEDON: Fairburn clay loam - on a convex, southeast-facing slope of 22 percent in range. When described the soil was dry throughout. (Colors are for dry soil unless otherwise stated)

A--0 to 4 inches; brown (10YR 5/3) clay loam, dark grayish brown (10YR 4/2) moist; weak very fine granular structure; soft, very friable, slightly sticky and slightly plastic; slight effervescence; moderately alkaline; clear smooth boundary. (3 to 5 inches)

AC--4 to 10 inches; grayish brown (10YR 5/2) clay loam, dark grayish brown (10YR 4/2) moist; weak medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; strong effervescence; moderately alkaline; clear wavy boundary. (0 to 8 inches)

C--10 to 15 inches; light brownish gray (2.5Y 6/2) clay loam, grayish brown (2.5Y 5/2) moist; massive; slightly hard, friable, slightly sticky and slightly plastic; 10 percent very fine grain sandstone fragments by volume; strong effervescence; strongly alkaline; clear wavy boundary.

Cr--15 to 60 inches; light gray (2.5Y 7/2) weathered very fine-grained sandstone, light brownish gray (2.5Y 6/2) moist; strong effervescence.

TYPE LOCATION: Pennington County, South Dakota; about 7 miles southeast of Scenic; 2300 feet north and 900 feet east of the southwest corner of section 5, T. 4 S., R. 14 E.

RANGE IN CHARACTERISTICS: The control section contains 18 to 35 percent clay. The depth to bedrock ranges from 10 to 20 inches. The depth to carbonates ranges from 0 to 4 inches. The EC ranges from 0 to 2 mmhos/cm throughout.

The A horizon has hue of 10YR or 2.5Y, value of 4 to 7 and 3 to 6 moist, and chroma of 1 to 4. It is silty clay loam, clay loam, loam, or silt loam. Reaction is neutral to moderately alkaline. Some pedons have up to 30 percent by volume of rock fragments.

The AC horizon has hue of 10YR, 2.5Y or 5Y, value of 4 to 7 and 3 to 6 moist, and chroma of 2 to 4. It is silty clay loam, clay loam, loam or silt loam. Reaction is slightly alkaline or moderately alkaline.

silty clay loam, clay loam, loam or silt loam. Fragments of siltstone or mudstone ranges from 0 to 15 percent by volume. Reaction ranges from slightly alkaline to strongly alkaline.

The Cr horizon has hue of 10YR, 2.5Y, or 5Y. Reaction is moderately alkaline or strongly alkaline. It is very fine-grained sandstone, siltstone, shale or mudstone.

COMPETING SERIES: These are the Dolcan, Menefee, Mittenbutte (T), Sipapu, Spearfish series. Dolcan soils occur at elevations above 6,200 feet and have precipitation that is distributed evenly throughout the year. Menefee soils have Bw horizons more than 6 inches thick. Mittenbutte soils contain less than 18 percent clay in the particle-size control section. Sipapu and Spearfish soils have hues of 7.5YR or redder below the A horizon. In addition, Sipapu soils have more than 15 percent pararock fragments in the particle-size control section.

GEOGRAPHIC SETTING: Fairburn soils are on gently sloping to very steep upland hills and ridges. Slopes generally are convex and range from 3 to 60 percent. The soil formed in residuum weathered from siltstone, very fine-grained sandstone, shale or mudstone. Mean annual air temperature ranges from 43 to 50 degrees F. Mean annual precipitation ranges from 12 to 18 inches, most of which occurs in the spring and early summer. Elevation ranges from 2,600 to 5,800 feet. Frost-free period ranges from 105 to 150 days.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Blackpipe, Metre, Norrest, Orella and Wortman soils. The Blackpipe, Metre, Norrest and Wortman soils have mudstone or shale at a depth below 20 inches and their particle-size control section contain more than 35 percent clay. In addition, the Blackpipe, Metre and Wortman soils have a mollic epipedon. They are on less sloping parts of the landscape below the Fairburn soils. Orella soils are on similar parts of the landscape as the Fairburn soils. Orella soils have a fine textured control section.

DRAINAGE AND PERMEABILITY: Well drained. Runoff is medium or high depending on slope. Permeability is moderate or moderately slow.

USE AND VEGETATION: Used primarily as rangeland. Native vegetation includes threadleaf sedge, needleleaf sedge, sideoats grama, blue grama, western wheatgrass, green needlegrass, yucca, and pricklypear.

DISTRIBUTION AND EXTENT: Southwestern South Dakota. The series is of moderate extent.

MLRA OFFICE RESPONSIBLE: Bismarck, North Dakota

SERIES ESTABLISHED: Pennington County, South Dakota, 1985.

REMARKS: Diagnostic horizons and features recognized in this pedon are: ochric epipedon - the zone from the surface of the soil to a depth of about 4 inches (A horizon).

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SAMSIL SERIES

The Samsil series consists of shallow, well drained soils formed in alluvium or residuum weathered from shale. Permeability is slow. Slope ranges from 2 to 60 percent. Mean annual precipitation is about 15 inches, and mean annual air temperature is about 47 degrees F.

TAXONOMIC CLASS: Clayey, smectitic, calcareous, mesic, shallow Aridic Ustorthents

TYPICAL PEDON: Samsil clay - on a convex, southwest-facing slope of 15 percent in native grass. When described the soil was moist to 12 inches, dry from 12 to 21 inches, and moist below 21 inches. (Colors are for dry soil unless otherwise stated)

A--0 to 2 inches; light brownish gray (2.5Y 6/2) clay, dark grayish brown (2.5Y 4/2) moist; moderate fine granular structure; slightly hard, friable, sticky and plastic; common fine roots; few very fine fragments of shale; slight effervescence; slightly alkaline; clear wavy boundary. (2 to 4 inches thick)

AC--2 to 7 inches; light brownish gray (2.5Y 6/2) clay, dark grayish brown (2.5Y 4/2) moist; weak medium subangular blocky structure parting to weak medium granular; hard, friable, sticky and plastic; common fine roots; common fine fragments of soft shale; slight effervescence; slightly alkaline; clear wavy boundary. (0 to 6 inches)

C1--7 to 11 inches; light brownish gray (2.5Y 6/2) clay, dark grayish brown (2.5Y 4/2) crushing to grayish brown (2.5Y 5/2) moist; massive; hard, friable, sticky and plastic; common fine roots; 30 percent by volume of fine and medium fragments of soft shale; few fine distinct olive yellow (2.5Y 6/6) stains on fragments of shale; slight effervescence; slightly alkaline; gradual wavy boundary.

C2--11 to 17 inches; light olive gray (5Y 6/2) clay, olive gray (5Y 5/2) moist; massive; hard, friable, sticky and plastic; common fine roots; about 50 percent by volume of fragments of soft shale; common distinct olive yellow (2.5Y 6/6) stains on faces of shale fragments; few fine and medium accumulations of carbonate; slight effervescence; moderately alkaline; gradual wavy boundary. (Combined C horizons 2 to 12 inches thick)

Cr--17 to 60 inches; light gray (5Y 7/2) shale; olive gray (5Y 5/2) moist; soft when moist but hard and brittle when dry; few fine roots in upper part; few iron and manganese stains in upper part.

TYPE LOCATION: Pennington County, South Dakota; about 3 miles east of Wasta; 1,515 feet east and 1,120 feet south of the northwest corner of sec. 12, T. 1 N., R. 14 E.; 24 feet south of C & GS BM J381 (1962) on west side of Jensen Road.

RANGE IN CHARACTERISTICS: The control section is clay and contains 50 to 65 percent clay. The depth to bedded shale ranges from 6 to 20 inches. Horizons above the shale range from loose to hard when dry, and friable or firm when moist. These horizons contain free carbonates. Effervescence

The A horizon has hue of 5Y, 2.5Y, or 10YR, value of 4 to 7 and 3 to 6 moist, and chroma of 2 to 4. It is clay, silty clay, silty clay loam or clay loam and commonly contains few to common fragments of shale ranging from 2 to 25 mm in diameter. It has fine or medium subangular blocky or fine or very fine granular structure. The upper 1/4 to 1/2 inch commonly is a fragile crust or mulch or very fine granules when dry.

The AC horizon has hue of 5Y, 2.5Y, or 10YR, value of 4 to 7 and 3 to 6 moist, and chroma of 1 to 4. It contains up to 35 percent fragments of shales by volume that range from less than 2 mm to 30 mm in diameter.

The C horizon has hue of 5Y, 2.5Y or 10YR, value of 4 to 7 and 3 to 6 moist, and chroma of 1 to 4. It is clay. The C horizon contains from 35 to more than 50 percent fragments of shale by volume that range from less than 2 mm to 35 mm in diameter.

The Cr horizon has the same range in color as the overlying C horizons. It ranges from medium acid to moderately alkaline.

COMPETING SERIES: These are the Epsie and Zigsag soils. Epsie soils have E and Bky horizons. Zigzag soils do not have carbonates, gypsum or salts.

GEOGRAPHIC SETTING: Samsil soils are on gently sloping to very steep hills, ridges and breaks of dissected shale plains. Surfaces mainly are convex, and slope gradients range from 2 to 60 percent or more. The soil formed in alluvium or residuum weathered from shale. Mean annual air temperature ranges from 45 to 48 degrees F, and mean annual precipitation ranges from 14 to 19 inches.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Cromack, Fairburn, Kyle, Nunn, Pierre, Satanta and Swanboy soils. Cromack and Pierre soils have bedrock between depths of 20 and 40 inches. In addition, Cromack soils have cambic horizons. Fairburn soils have a loamy particle-size control section. Kyle soils have bedrock at depths greater than 40 inches. Nunn soils have a fine textured argillic horizon. Satanta soils have a fine-loamy particle-size control section. Swanboy soils have visible salts within 10 inches of the surface. Kyle and Pierre soils are on smoother parts of nearby landscapes. Nunn and Satanta soils are on flats above the Samsil soils. Swanboy soils are on toeslopes and flats below the Samsil soils.

DRAINAGE AND PERMEABILITY: Well drained. Surface runoff ranges from medium to very high depending on slope. Permeability is slow.

USE AND VEGETATION: Rangeland. Native vegetation is mainly little bluestem, western wheatgrass, sideoats grama, blue grama, green needlegrass, sedges, and forbs.

DISTRIBUTION AND EXTENT: Southwestern South Dakota and parts of Nebraska and Wyoming. The soil is extensive.

MLRA OFFICE RESPONSIBLE: Bismarck, North Dakota

SERIES ESTABLISHED: Stanley County, South Dakota, 1967.

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MULEHERDER SERIES

The Muleherder series consists of very deep, well drained soils formed in alluvium derived from porcelanite. Muleherder soils are on hills, knolls and ridges. Slopes range from 0 to 75 percent. The mean annual precipitation is about 16 inches, and the mean annual air temperature is about 47 degrees F.

TAXONOMIC CLASS: Loamy-skeletal over fragmental, mixed, superactive, mesic Aridic Haplustepts

TYPICAL PEDON: Muleherder channery loam - utilized as range land. (Colors are for dry soils unless otherwise stated)

A--0 to 2 inches; reddish brown (5YR 4/3) channery loam, dark reddish brown (5YR 3/3) moist; weak fine granular structure; slightly hard, friable, nonsticky and nonplastic; 15 percent angular porcelanite channers; neutral; clear smooth boundary. (2 to 6 inches thick)

Bw1--2 to 12 inches; reddish brown (5YR 4/4) channery loam, dark reddish brown (5YR 3/4) moist; weak fine and medium subangular blocky structure; slightly hard, friable, nonsticky and nonplastic; 15 percent angular porcelanite channers; neutral; clear smooth boundary.

Bw2--12 to 16 inches; red (2.5YR 5/6) channery loam, red (2.5YR 4/6) moist; weak fine subangular blocky structure; slightly hard, friable, nonsticky and nonplastic; 20 percent angular porcelanite channers; neutral; clear wavy boundary. (Combined Bw horizons 6 to 20 inches thick)

BCk1--16 to 28 inches; light reddish brown (5YR 6/4) very channery fine sandy loam, reddish brown (5YR 5/4) moist; massive; loose, loose, nonsticky and nonplastic; few distinct discontinuous light gray (10YR 7/2) carbonate coats on rock fragments; strongly effervescent; 40 percent angular porcelanite channers; moderately alkaline; clear wavy boundary.

BCk2--28 to 33 inches; red (2.5YR 5/6) extremely channery fine sandy loam, red (2.5YR 4/6) moist; massive; loose, loose, nonsticky and nonplastic; few distinct discontinuous light gray (10YR 7/2) carbonate coats on rock fragments; strongly effervescent; 65 percent angular porcelanite channers; moderately alkaline; clear wavy boundary. (Combined BCk horizons 0 to 20 inches thick)

2C--33 to 80 inches; fractured porcelanite.

TYPE LOCATION: Campbell County, Wyoming; about 200 feet west and 900 feet south of the northeast corner of Sec. 7, T 57 N, R 73 W.; USGS Corral Creek, WY topographic quadrangle; lat. 44 degrees 56 minutes 36 seconds N. and long. 105 degrees 40 minutes 31 seconds W.

RANGE IN CHARACTERISTICS: Depth to the fragmental substratum ranges from 20 to 40 inches. Depth to carbonates ranges from 0 to 24 inches. The fragmental materials in some pedons are inconsistently calcareous. The weighted average organic carbon content of the surface 15 inches or that diameter. These are devoid of any fine earth material.

The A horizon has hue of 5YR, 7.5YR or 10YR, value of 4 to 7 dry, 3 to 6 moist, and chroma of 2 to 6. When the value of the A horizon is as dark as 5 dry and 3 moist, the horizon is too thin or contains too little organic matter to be a mollic epipedon. Texture is channery loam, very channery loam, loam, channery fine sandy loam, very channery fine sandy loam or fine sandy loam. Reaction is neutral or slightly alkaline. Rock fragments range from 0 to 40 percent, with 0 to 5 percent flagstones and stones. Some pedons have an AC horizon.

The Bw and BCK horizons have hue of 2.5YR, 5YR, 7.5YR or 10YR, value of 4 to 7 dry, 3 to 6 moist, and chroma of 3 to 6. Texture is channery to extremely channery, loam, sandy clay loam, silt loam, clay loam or fine sandy loam. Reaction is neutral to moderately alkaline. Rock fragments range from 15 to 90 percent, with 0 to 5 percent stones and 0 to 15 percent flagstones. Some pedons have a C horizon above the Cr horizon.

The 2C horizon consists of fractured or collapsed porcelanite beds. Fine earth material is uncommon but when present is less than 5 percent. Colors of the rock are quite variable but commonly have 10R or 2.5YR hue. Hues of 5YR have been recorded in some areas. Flagstones make up from 15 to 45 percent and channers 50 to 85 percent of this horizon.

COMPETING SERIES: There are no competing series in the same family.

GEOGRAPHIC SETTING: The Muleherder series occurs on hills, knolls, and the crests and shoulders of ridges. Slopes range from 0 to 75 percent. The soil formed in moderately deep, medium to moderately fine textured, channery materials weathered principally from beds of porcelanite. The average annual precipitation ranges from 15 to 17 inches with peak periods of precipitation occurring in April, May, and June. The mean annual air temperature ranges from 44 to 50 degrees F., and the mean summer temperature is 65 degrees F. Elevation is 3,500 to 5,800 feet. The frost-free season is 105 to 130 days.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Deekay, Fairburn, Ironbutte (T), Mittenbutte and Moorhead soils. Deekay and Moorhead soils occur on uplands and footslopes. Fairburn, Ironbutte and Mittenbutte occur on similar positions as Muleherder soils. Deekay, Fairburn, Mittenbutte and Moorhead soils lack fragmental discontinuities. In addition, Deekay and Moorhead soils have argillic horizons. Ironbutte soils are shallow to fractured porcelanite.

DRAINAGE AND PERMEABILITY: Well drained; runoff is negligible to high depending on slope; permeability is moderate over very rapid.

USE AND VEGETATION: They are used as native rangeland. Native vegetation includes sage, prairie junegrass, Sandberg bluegrass and needleandthread.

DISTRIBUTION AND EXTENT: Northeastern Wyoming and possibly southeastern Montana, and western South Dakota. The series is of moderate extent.

MLRA OFFICE RESPONSIBLE: Bismarck, North Dakota.

SERIES ESTABLISHED: Campbell County, Southern Part, Wyoming, 2001.

Cambic horizon - 2 to 16 inches (Bw1 and Bw2 horizons)

Fragmental discontinuity - 33 inches (top of 2C horizon)

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IRONBUTTE SERIES

The Ironbutte series consists of very deep, somewhat excessively drained soils formed in material derived from porcelanite. Ironbutte soils are on hills, knolls and ridges. Slopes range from 0 to 75 percent. The mean annual precipitation is about 16 inches, and the mean annual air temperature is about 47 degrees F.

TAXONOMIC CLASS: Loamy-skeletal over fragmental, mixed, superactive, nonacid, mesic Aridic Ustorthents

TYPICAL PEDON: Ironbutte channery loam - on a 15 percent southwest facing slope utilized as range land. (Colors are for dry soils unless otherwise stated)

A--0 to 4 inches; light reddish brown (5YR 6/3) channery loam, reddish brown (5YR 4/3) moist; moderate very fine granular structure; soft, very friable; 20 percent channers; slightly alkaline (pH 7.4); clear smooth boundary. (3 to 6 inches thick)

C--4 to 12 inches; light reddish brown (5YR 6/4) very channery loam, reddish brown (5YR 4/4) moist; massive; soft, very friable; 55 percent channers 1/2 to 5 inches in length; slightly alkaline (pH 7.4); clear wavy boundary. (4 to 17 inches thick)

2C--12 to 60 inches; fractured porcelanite. Intricacies between coarse fragments are void of fines.

TYPE LOCATION: Campbell County, Wyoming; about 660 feet north and 250 feet west of the southeast corner of Sec. 19, T 50 N, R 71 W.; USGS Gillette East, WY topographic quadrangle; lat. 44 degrees 17 minutes 33 seconds N. and long. 105 degrees 25 minutes 47 seconds W.

RANGE IN CHARACTERISTICS: Depth to the fragmental material ranges from 7 to 20 inches. These soils are typically noncalcareous throughout the loamy-skeletal part of the control section but some pedons have carbonates within 6 inches. The fragmental materials in some pedons are inconsistently calcareous. The weighted average organic carbon content of the material above the fragmental beds ranges from approximately 0.4 to 1.0 percent. Conductivity is typically less than 2 mmhos/cm and exchangeable sodium percentage is normally less than 3 percent. The mean annual soil temperature ranges from 47 to 53 degrees F. The soil temperature at 20 inches is 41 degrees F. or higher for 175 to 210 days. The fragmental material contains interstices ranging from 2 mm to over 2 cm in diameter. These are devoid of any fine earth material.

The A horizon has hue of 5YR, 7.5YR or 10YR, value of 5 to 7, 3 to 6 moist, and chroma of 2 to 6. When the A horizon has a value of 5 dry and 3 moist, it is too thin or contains too little organic matter to be a mollic epipedon. Texture is channery loam, very channery loam, loam, channery fine sandy loam, very channery fine sandy loam or fine sandy loam. Rock fragments range from 5 to 40 percent, with 0 to 5 percent flagstone. Reaction is neutral or slightly alkaline. Some pedons have an AC horizon.

related to soil development characteristic of a cambic horizon. Texture is very channery loam, extremely channery loam, very channery fine sandy loam or extremely channery fine sandy loam. Rock fragments range from 35 to 90 percent, with 0 to 15 percent flagstones and 0 to 5 percent stones. Reaction is neutral to slightly alkaline. Moderately alkaline reactions may occur where the horizon is derived from sodic porcelanite.

The 2C horizon consists of fractured and/or collapsed porcelanite beds. A fine-earth matrix is uncommon, but when present is less than 5 percent. Colors of the rock are quite variable but commonly have 10R or 2.5YR hue. Hues of 5YR have been recorded in some areas.

COMPETING SERIES: This is the Muleherder series. Muleherder soils are moderately deep to fragmental, porcelanite beds.

GEOGRAPHIC SETTING: The Ironbutte series occurs on hills, knolls and the crests and shoulders of ridges. Slopes range from 0 to 75 percent. The soil is developing in thin mantels of medium to moderately fine textured, noncalcareous, channery materials weathered principally from porcelanite beds. The average annual precipitation ranges from 15 to 17 inches with peak periods of precipitation occurring in April, May, and June. The mean annual air temperature ranges from 44 to 50 degrees F., and the mean summer temperature is 65 degrees F. Elevation is 3,500 to 5,800 feet. The frost-free season is 105 to 130 days.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Deekay, Fairburn, Mittenbutte (T), Muleherder (T) and Ucross soils. The Deekay soils have argillic horizons and lack fragmental discontinuities. Fairburn, Mittenbutte and Ucross soils lack fragmental discontinuities. Muleherder soils are moderately deep to fractured porcelanite. Deekay occur on flats and footslopes. Fairburn, Mittenbutte, Muleherder and Ucross soils occur on similar positions as Ironbutte soils.

DRAINAGE AND PERMEABILITY: Somewhat excessively drained; runoff is negligible to high depending on slope; permeability is moderate over very rapid.

USE AND VEGETATION: They are used as native rangeland. Native vegetation includes sage, prairie junegrass, Sandberg bluegrass, and needleandthread. Some pedons have ponderosa pine and juniper.

DISTRIBUTION AND EXTENT: Northeastern Wyoming and possibly adjacent areas of Montana and South Dakota. The series is of moderate extent.

MLRA OFFICE RESPONSIBLE: Bismarck, North Dakota.

SERIES ESTABLISHED: Campbell County, Southern Part, Wyoming; 2001.

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

Ochric epipedon - 0 to 3 inches (A horizon)

Fragmental discontinuity - 16 inches (top of 2C horizon)

APPENDIX B: WATER QUALITY MONITORING DATA

Produced Water Quality (Homestead Draw II)

Bitter Creek Water Quality (WQMS TRIB 1)

Bitter Creek Water Quality (Non-WQMS SW_BitterCK)

Project: Homestead Draw II | Report Date: 10/16/07
Client Sample ID: 3CK-14-5674 | Collection Date: 09/28/07 12:00
Location: | DateReceived: 09/28/07
Samp FRQ/Type: | Matrix: Aqueous
Lab ID: G07090870-001 | Sampled By: Ralph Combs

Analyses	Result	Units	Result	Units	Qualifier	Method	Analysis Date / By
MAJOR IONS, DISSOLVED							
Bicarbonate as HCO3	1060	mg/L	17.4	meq/L		A2320 B	10/01/07 11:21 / mli
Chloride	26	mg/L	0.73	meq/L		E300.0	10/01/07 19:48 / mjh
Fluoride	0.8	mg/L	0.04	meq/L		E300.0	10/01/07 19:48 / mjh
Sulfate	3	mg/L	0.07	meq/L		E300.0	10/01/07 19:48 / mjh
Calcium	16	mg/L	0.78	meq/L		E200.7	10/02/07 22:20 / eli-b
Magnesium	8	mg/L	0.64	meq/L		E200.7	10/02/07 22:20 / eli-b
Potassium	6	mg/L	0.16	meq/L		E200.7	10/02/07 22:20 / eli-b
Sodium	398	mg/L	17.3	meq/L		E200.7	10/02/07 22:20 / eli-b
METALS, DISSOLVED							
Boron	<100	ug/L				E200.7	10/02/07 22:20 / eli-b
Cadmium	<0.1	ug/L				E200.8	10/11/07 04:28 / eli-b
Chromium	<1	ug/L				E200.8	10/11/07 04:28 / eli-b
Copper	1	ug/L				E200.8	10/11/07 04:28 / eli-b
Iron	265	ug/L				E200.7	10/02/07 22:20 / eli-b
Lead	<2	ug/L				E200.8	10/11/07 04:28 / eli-b
Manganese	32	ug/L				E200.7	10/02/07 22:20 / eli-b
Mercury	<0.06	ug/L				E200.8	10/11/07 04:28 / eli-b
Nickel	<10	ug/L				E200.7	10/02/07 22:20 / eli-b
Silver	<3	ug/L				E200.8	10/11/07 04:28 / eli-b
Zinc	21	ug/L				E200.8	10/11/07 04:28 / eli-b
METALS, TOTAL RECOVERABLE							
Aluminum	<50	ug/L				E200.8	10/11/07 04:36 / eli-b
Antimony	<5	ug/L				E200.8	10/11/07 04:36 / eli-b
Arsenic	<0.5	ug/L				E200.8	10/11/07 04:36 / eli-b
Barium	350	ug/L				E200.8	10/11/07 04:36 / eli-b
Beryllium	<0.03	ug/L				E200.8	10/11/07 04:36 / eli-b
Selenium	<5	ug/L				E200.8	10/11/07 04:36 / eli-b
Thallium	<1	ug/L				E200.8	10/11/07 04:36 / eli-b
NON-METALS							
Alkalinity, Total as CaCO3	872	mg/L				A2320 B	10/01/07 11:21 / mli
Conductivity @ 25 C	1620	umhos/cm				A2510 B	09/28/07 17:14 / mtb
Cyanide, Total	<5	ug/L				Kelada mod	10/03/07 10:13 / eli-b
Hardness as CaCO3	71	mg/L				A2340 B	10/11/07 11:07 / tlc
pH	7.66	s.u.				A4500-H B	09/28/07 17:15 / mtb
Phenolics, Total Recoverable	<10	ug/L				E420.2	10/02/07 11:53 / eli-b
Sodium Adsorption Ratio (SAR)	20.5	unitless				Calculation	10/11/07 11:07 / tlc
Solids, Total Dissolved TDS @ 180 C	995	mg/L				A2540 C	10/01/07 09:08 / mli
Total Petroleum Hydrocarbons	<1.0	mg/L				E1664A	10/05/07 12:51 / wet

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

Client Sample ID: 3CK-14-5674
Location:
Samp FRQ/Type:
Lab ID: G07090870-001

Collection Date: 09/28/07 12:00
DateReceived: 09/28/07
Matrix: Aqueous
Sampled By: Ralph Combs

Analyses	Result	Units	Result	Units	Qualifier	Method	Analysis Date / By
RADIONUCLIDES - TOTAL							
Radium 226	27	pCi/L				E903.0M	10/08/07 15:56 / eli-c
Radium 226 precision (±)	1.0	pCi/L				E903.0M	10/08/07 15:56 / eli-c
DATA QUALITY							
A/C Balance	-1.31	%				A1030 E	10/11/07 11:06 / tlc
Anions	19.4	meq/L				A1030 E	10/11/07 11:06 / tlc
Cations	18.9	meq/L				A1030 E	10/11/07 11:06 / tlc
BACTERIA							
Bacteria, Sulfate Reducing	1000	col/ml				INDICATOR	09/28/07 14:30 / wet

Michelle Bucholz

Michelle Bucholz
Project Manager

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

Site Name:	S_Joe_Creek	**Report Date:**	05/23/07
Project:	WYPDES_WQMS	**Collection Date:**	05/14/07 11:00
Client Sample ID:	DP_BitterCk_WY0052523_Trib1	**DateReceived:**	05/16/07
Location:	SENW_23_58N_75W	**Sampled By:**	Todd Adams
Samp FRQ/Type:	M	**Matrix:**	AQUEOUS
Lab ID:	G07050556-001	**Tracking Number:**	102949

Analyses	Result	Units	Result	Units	Qualifier	Method	Analysis Date / By
FIELD PARAMETERS							
Flow	0.851	mgd				FIELD	05/14/07 11:00 / ***
pH, field	8.30	s.u.				FIELD	05/14/07 11:00 / ***
Temperature °C, field	17.2	Deg C				FIELD	05/14/07 11:00 / ***
Temperature °F, field	63.0	Deg F				FIELD	05/14/07 11:00 / ***
*** Performed by Sampler							
MAJOR IONS, DISSOLVED							
Calcium	169	mg/L	8.44	meq/L		E200.7	05/22/07 05:34 / eli-b
Magnesium	177	mg/L	14.5	meq/L		E200.7	05/22/07 05:34 / eli-b
Sodium	420	mg/L	18.3	meq/L		E200.7	05/22/07 05:34 / eli-b
NON-METALS							
Conductivity @ 25 C	3430	umhos/cm				A2510 B	05/16/07 11:53 / mtb
Sodium Adsorption Ratio (SAR)	5.4	unitless				Calculation	05/23/07 08:53 / tlc

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

Project:	Surface_Water	**Collection Date:**	05/18/07 10:00
Client Sample ID:	SW_BitterCk	**DateReceived:**	05/22/07
Location:	NESE_22_57N_74W	**Sampled By:**	Manoj Patil
Samp FRQ/Type:	SP	**Matrix:**	Aqueous
Lab ID:	G07050760-001	**Tracking Number:**	100391

Analyses	Result	Units	Result	Units	Qualifier	Method	Analysis Date / By
MAJOR IONS, DISSOLVED							
Bicarbonate as HCO3	642	mg/L	10.5	meq/L		A2320 B	05/23/07 18:52 / mli
Chloride	39	mg/L	1.09	meq/L		E300.0	05/29/07 13:05 / mli
Fluoride	0.4	mg/L	0.02	meq/L		E300.0	05/29/07 13:05 / mli
Sulfate	4800	mg/L	99.9	meq/L		E300.0	05/24/07 14:31 / mli
Calcium	263	mg/L	13.1	meq/L		E200.7	05/25/07 23:36 / eli-b
Magnesium	536	mg/L	44.1	meq/L		E200.7	05/25/07 23:36 / eli-b
Potassium	25	mg/L	0.64	meq/L		E200.7	05/25/07 23:36 / eli-b
Sodium	1350	mg/L	58.6	meq/L		E200.7	05/25/07 23:36 / eli-b
NON-METALS							
Alkalinity, Total as CaCO3	526	mg/L				A2320 B	05/23/07 18:52 / mli
Conductivity @ 25 C	8170	umhos/cm				A2510 B	05/22/07 15:38 / jjb
Sodium Adsorption Ratio (SAR)	11.0	unitless				Calculation	05/30/07 12:48 / tlc
DATA QUALITY							
A/C Balance	2.16	%				A1030 E	05/30/07 12:47 / tlc
Anions	112	meq/L				A1030 E	05/30/07 12:47 / tlc
Cations	116	meq/L				A1030 E	05/30/07 12:47 / tlc

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

APPENDIX C: ORIGINAL LABORATORY SOILS REPORTS FROM LATEST SAMPLING (KC HARVEY, INC., DECEMBER, 2007)

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

Termo Co
Bitter Creek Sec 20
H07120123

Report Date: 01/03/08
Date Received: 12/12/07

Analysis			pH-SatPst	COND	Percent Sat	SAR	HCO3 SatPst	Ca-SatPst	Mg-SatPst	Na-SatPst	Sand	Silt	Clay
Units			s_u_	mmhos/cm	%	unitless	meq/L	meq/l	meq/l	meq/l	%	%	%
Client Sample ID	**Up**	**Low**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**
Crockett Field 4 & 5 0-12"	0	0	7.4	1.35	65.0	1.8	5.31	4.55	4.30	3.75	10	52	38
Crockett Field 4 & 5 12-24"	12	24	7.8	6.38	55.8	9.0	3.94	18.6	26.0	42.5	12	56	32
Crockett Field 4 & 5 24-36"	24	36	8.3	8.92	59.3	16	1.48	15.1	39.0	82.7	18	54	28
Crockett Field 4 & 5 36-48"	36	48	8.3	8.87	61.0	16	1.67	15.1	34.0	77.0	16	56	28
Crockett Field 4 & 5 48-60"	48	60	8.1	7.82	54.3	13	1.57	17.7	32.4	65.4	22	52	26
Crockett Field 4 & 5 60-72"	60	72	8.1	7.51	52.8	13	2.16	18.6	31.4	63.9	26	49	25

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LABORATORY ANALYTICAL REPORT

Termo Co
Bitter Creek Sec 20
H07120123

Report Date: 01/03/08
Date Received: 12/12/07

Analysis			Texture	OM-WB	CEC	Lime	Na-Ext	Exch Na	ESP
	Units		unitless	%	meq/100g	%	meq/100g	meq/100g	%
Client Sample ID	**Up**	**Low**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**
Crockett Field 4 & 5 0-12"	0	0	SiCL	3.56	29.1	4.4	1.09	0.8	2.9
Crockett Field 4 & 5 12-24"	12	24	SiCL	1.87	22.1	5.3	5.39	3.0	14
Crockett Field 4 & 5 24-36"	24	36	SiCL	1.34	27.8	5.4	9.98	5.0	18
Crockett Field 4 & 5 36-48"	36	48	SiCL	1.40	22.8	5.5	9.59	4.9	21
Crockett Field 4 & 5 48-60"	48	60	SiL	1.15	22.4	5.2	6.93	3.4	15
Crockett Field 4 & 5 60-72"	60	72	L	1.08	23.7	5.0	6.28	2.9	12

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LABORATORY ANALYTICAL REPORT

Termo Co
Bitter Creek Sec 20
H07120122

Report Date: 01/03/08
Date Received: 12/12/07

Analysis			pH-SatPst	COND	Percent Sat	SAR	HCO3 SatPst	Ca-SatPst	Mg-SatPst	Na-SatPst	SO4-SatPst	Sand	Silt
Units			s_u_	mmhos/cm	%	unitless	meq/L	meq/l	meq/l	meq/l	meq/l	%	%
Client Sample ID	**Up**	**Low**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**
Crockett Field Sub 2 0-12"	0	12	7.9	7.54	65.7	12	3.74	18.9	30.0	57.3	103	6	57
Crockett Field Sub 2 12-24"	12	24	8.2	11.8	63.0	17	1.97	18.2	40.9	94.6	151	8	60
Crockett Field Sub 2 24-36"	24	36	8.2	10.7	60.7	16	2.16	18.7	43.1	88.4	147	12	58
Crockett Field Sub 2 36-48"	36	48	8.0	7.60	63.0	12	1.57	16.5	31.3	58.6	107	12	56
Crockett Field Sub 2 48-60"	48	60	8.0	8.30	59.5	12	1.77	19.0	30.8	60.9	107	22	49
Crockett Field Sub 2 60-72"	60	72	8.0	6.11	58.8	10	1.87	15.8	24.5	45.4	82.8	13	53

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LABORATORY ANALYTICAL REPORT

Termo Co
Bitter Creek Sec 20
H07120122

Report Date: 01/03/08
Date Received: 12/12/07

		Analysis		Clay	Texture	OM-WB	CEC	Lime	Na-Ext	Exch Na	ESP
		Units		%	unitless	%	meq/100g	%	meq/100g	meq/100g	%
	Client Sample ID	Up	Low	Results	Results	Results	Results	Results	Results	Results	Results
1	Crockett Field Sub 2 0-12"	0	12	37	SiCL	2.15	30.7	5.7	7.76	4.0	13
2	Crockett Field Sub 2 12-24"	12	24	32	SiCL	1.09	25.8	5.7	10.6	4.7	18
3	Crockett Field Sub 2 24-36"	24	36	30	SiCL	1.19	26.5	5.3	10.1	4.8	18
4	Crockett Field Sub 2 36-48"	36	48	32	SiCL	1.28	25.0	4.5	7.24	3.6	14
5	Crockett Field Sub 2 48-60"	48	60	29	CL	1.22	25.2	4.9	6.89	3.3	13
6	Crockett Field Sub 2 60-72"	60	72	34	SiCL	0.94	20.8	5.0	6.01	3.3	16