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FINAL REPORT
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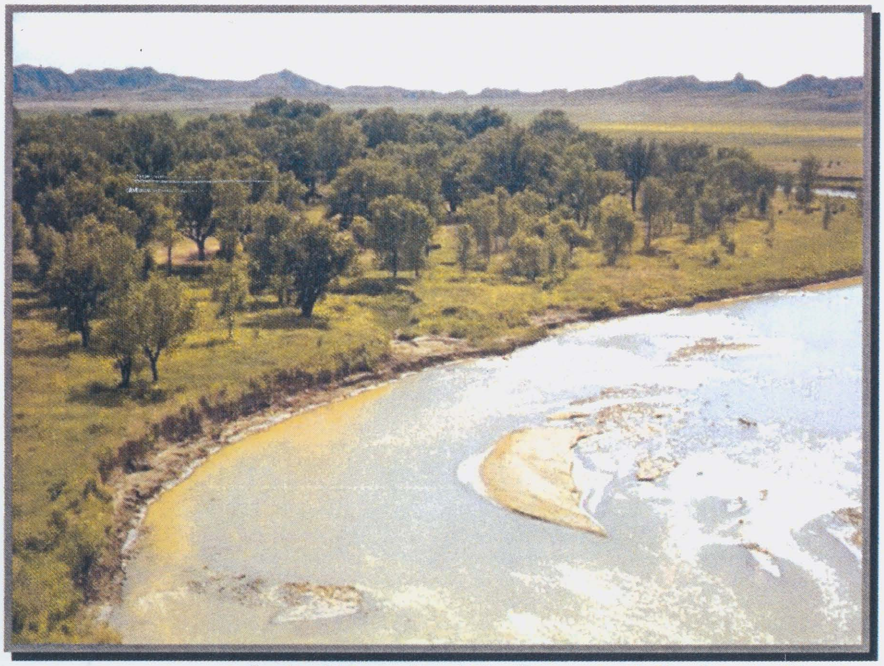

Spotted Horse Creek Confluence with the Powder River

THREE HORSES WATERSHED PLAN

LEVEL I STUDY

Prepared for:
Wyoming Water Development Commission

Submitted by:
EnTech, Inc.
Consulting Engineers
Sheridan, Wyoming
in association with
Environmental Design Engineering
RIMCON, L.L.C.

December, 2002

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THREE HORSES WATERSHED PLAN

LEVEL I STUDY

Professional Engineer (Civil) DAVID ENGELS 3375 Date WYOMING

PROFESSIONAL GEOLOGIST BENJAMIN J. SCHIFFER PG-3446 WYOMING

Professional Engineer (Civil) BRUCE N. NELSON 4865 Date WYOMING

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1. INTRODUCTION

1.1 Background and Need

In September 2000, the Lake DeSmet Conservation District (LDCD) and Campbell County Conservation District (CCCD), in cooperation with local landowners, industry, and state and federal agencies, submitted a joint application to the Wyoming Water Development Commission (WWDC) to develop management plans for three watersheds that are tributary to the Powder River in northeastern Wyoming. These watersheds are the Dead Horse Creek Watershed (DHCW), Wild Horse Creek Watershed (WHCW) and Spotted Horse Creek Watershed (SHCW), together known as "the Three Horses". The principal reason that these diverse groups outlined above submitted this application was due to their concern about the potential cumulative impacts of existing and future development of coal bed methane gas (CBM) in the three basins.

CBM development is one of the critical issues currently facing the Three Horses watersheds. With the ever-increasing demand for energy sources by the United States, there is little doubt that the important energy reserves within the Powder River Basin (PRB), of which CBM is a significant part, will be developed. It is estimated that 25 trillion cubic feet of CBM can potentially be recoverable within the PRB, of which the Three Horses watersheds encompass a significant part. (U.S. Department of Interior, BLM 2002) Coal seams are abundant in the area, and natural gas transmission mains have already been and are continually being constructed within the PRB that can convey this energy source to distant markets. However, due to the need to depressurize the coal formation within which the CBM resides in order to extract the CBM, it is necessary to remove large quantities of groundwater in order to make available the CBM. The extraction process and its associated activities are perceived as having a significant hydrologic and environmental impacts upon this basin, of which the Three Horses are a part.

As of August 2002, over 9,000 CBM wells have been permitted in the PRB by the State of Wyoming Oil and Gas Conservation Commission (WO&GCC). Of this number, approximately 3400 wells have been permitted in the Three Horses. (WO&GCC 2002) Estimates place the total number of CBM wells to eventually be drilled in the PRB at over 51,000. (U.S. Department of Interior, BLM) Based upon this estimate, it is possible that up to 7.5 trillion gallons (23 million acre-feet) of water could eventually be extracted in order to facilitate this gas extraction. (McBeth, et al 2002)

Although CBM development is occurring in several areas within Wyoming, the current focus is within northeastern Wyoming, and Campbell, Johnson and Sheridan Counties in particular. The DHCW is located within Campbell and Johnson Counties, and both the WHCW and SHCW are located within Campbell and Sheridan Counties. Thus it is understandable that the conservation districts within these counties have taken a considerable interest in protecting these watersheds from impacts that may occur as a result of this development.

1.2 Scope of Work

On June 4, 2001, after proceeding through a procurement and negotiation process, the WWDC contracted with EnTech to perform the Level I study of the Three Horses area. The scope of work identified for this study includes the following tasks:

- *Review of existing background information available through the numerous federal, state and local agencies that are involved to some extent with CBM development in the PRB and within the Three Horses drainages in particular.*
- *Compile the background information available through these agencies defined above.*
- *Collect data necessary to augment the background information defined above.*
- *Evaluate the most effective and feasible options for management of the Three Horses*

watersheds.

- *Develop reconnaissance level cost estimates of suggested management options.*
- *Identify any necessary permits required to implement the management options evaluated.*
- *Provide information on potential funding sources for implementation of specific management options and improvement projects.*

The results of the first three tasks are presented in Section 2 of this report entitled, "Descriptions of Watersheds," which addresses the general characteristics of the three watersheds. Section 2 of the report is formatted to address each of the three watersheds separately with respect to geography/topography, land ownership, mineral ownership, geology, soils, vegetation, surface water, and groundwater. Section 3 relates the perceived and potential impacts from CBM activities in the Three Horses watersheds, an understanding of which is important in the assessment of potential water management alternatives. An evaluation of the most effective and feasible watershed management alternatives and cost estimates associated with these options are provided in Section 4 of the report. Included within this section is a listing of the permits that are considered to be necessary to implement the respective water management alternative. Section 5 provides an analysis of these water management alternatives and a recommended plan for the watersheds. Section 6 portrays a project financing plan in the event that implementation of the recommended plan(s) involves public sector financing. Finally, Section 7 provides a summary of this Level I study and a path forward for the project sponsors to consider following.

2. DESCRIPTIONS OF WATERSHEDS

The Three Horses watersheds encompass lands within northeastern Wyoming, and Campbell, Johnson and Sheridan Counties in particular (See Figure 2.1). The total area of the Three Horses watersheds is approximately 614 square miles. These three watersheds lie within the larger Upper Powder River watershed, the United States Geological Survey's (USGS) 8-digit Hydrologic Unit Code (HUC) Number for the Upper Powder River watershed being 10090202. Each of the three watersheds is described more fully below.

2.1 DEAD HORSE CREEK

2.1.1 Geography and Topography

The DHCW is located within Campbell and Johnson Counties. It extends upstream from the Powder River in an easterly and southerly direction, with the confluence being approximately two miles northeast of Interstate 90's (I-90) crossing of the Powder River. Figure 2.1.1 depicts the watershed boundary and the enclosed 98,360 acres (approximately 154 square miles).

The highest elevation in the watershed is 5,184 feet, located in Section 35, T49N, R74W. The confluence with the Powder River is the lowest point in the watershed, which is at elevation 3,920 feet. The total elevation difference is thus 1,264 feet over a horizontal distance of approximately 24 miles (52.7 feet/mile, or an average valley slope of 1.0%).

2.1.2 Surface Ownership

Figure 2.1.2 depicts the surface ownership within the Three Horses drainage areas. (U.S. Department of Interior, BLM 2002) The amount of land and percentage of surface ownership among federal, state and private interests in the DHCW is as shown in Table 2.1.1.

Table 2.1.1
Dead Horse Creek Watershed Surface Ownership

Ownership	Area (sq. mi.)	%
Federal	29.2	19.0
State	2.7	1.8
Private	121.7	79.2
Totals	153.6	100

Of the private ownership within the DHCW, there are eleven different property owners. (Gene George and Associates 2001) These property owners maintain leases for the surface use of the various federally and state owned lands.

2.1.3 Minerals Ownership

Figure 2.1.3 portrays the ownership of federal minerals within the Three Horses drainage areas in relation to other mineral ownerships. (U.S. Department of Interior, BLM 2002) The amount of land and percentage of minerals ownership between federal and other interests within the DCHW is as follows:

Table 2.1.2
Dead Horse Creek Watershed Minerals Ownership

Ownership	Area (sq. mi.)	%
Federal	123.9	81
Other (Private, State)	29.7	19
Totals	153.6	100

As can be seen, there is an overriding majority of federal mineral ownership within the DHCW.

2.1.4 Geology

Figure 2.1.4 portrays the surface geology of the Three Horses drainage areas, including the DHCW. (U.S. Department of Interior, BLM 2002) Located within the PRB structural basin, the DHCW portrays typical geologic features of the area. Recent or Quaternary alluvium along the main channel of DHCW overlays the surficial geologic unit, the Eocene age Wasatch Formation. Alluvium in the DHCW is composed of eroded detritus from the Wasatch, and includes silty clays, silts and sands typical of stream and/or flood plain deposits. Covering the entire drainage (except for the main channel areas and local colluvial deposits) is the Wasatch Formation. Deposited following uplifts associated with the Laramide Orogenic event, the mudstones, sandstones and coals represent erosion and subsequent deposition from various types of processes. (Seeland 1992) Sandstones comprise an estimated one-third of the Wasatch, though the units are interbedded with both finer grained silts and clays as well as thin coal seams in the DHCW. WO&GCC data indicates the presence of Wasatch coals such as the Felix and Badger in the DHCW, although the authors are unaware of any CBM production from the intervals. Approximate thickness of the Wasatch in the DHCW ranges from 700-900 feet. (WO&GCC 2002) Figure 2.1.5 portrays the stratigraphic nomenclature of the PRB.

Composed of three primary members, the Paleocene Fort Union Formation represents an earlier phase of erosion and deposition in the PRB. From stratigraphic top to bottom, the members include the Tongue River, Lebo Shale, and Tullock. The Tongue River Member, comprised primarily of sandstones and thick coal seams, represents erosion of the Black Hills Uplift and swampy environments associated with quiet episodes during deposition. (Flores and Ethridge 1985; Flores 1986) Coals within the Tongue River Member from top to bottom are the Wyodak-Anderson, Canyon, Cook, Wall and Pawnee. Thickness of the Tongue River Member approaches 2,000 feet in the DHCW. Approximately midway from east to west, these coals merge into the Big George Coal. (Gene George and Associates 2001) The general dip of the formation within the DHCW is to the west at approximately 1^0.

The majority of CBM production in the DHCW drainage is anticipated to come from the Wyodak coals. (WO&GCC 2002) WO&GCC data indicates that wells completed in the Big George have an average completion of 60 feet that can vary from 16 feet to 110 feet. Values for the deeper Wyodak indicate an average thickness of 54 feet, with intervals ranging from 5 feet to 160 feet. Table 2.1.3 provides a summary of the coal seam thicknesses within the DHCW, based upon WO&GCC data.

Table 2.1.3
DHCW Coal Seam Thickness Summary

Coal Seam	Number of Data Points	Mean Thickness (ft)	Maximum Thickness (ft)	Minimum Thickness (ft)
Wyodak	81	53.5	160	5
Big George	38	59.6	110	16

The Lebo Member of the Fort Union represents middle Paleocene deposition. Deposited in a lower energy environment, the Lebo is primarily comprised of dark shales and sparse channel sandstones with a few thin coal seams (less than two feet). (Law 1975; Lewis and Hotchkiss 1981) Underlying the Lebo is the Tullock Member of the Fort Union. Representing earliest Paleocene deposition, stream sediments dominate the Tullock; the fine-grained sandstones, siltstones, shales and minor coals portray sequences of uplift, erosion and stabilization in the PRB. (Curry 1971)

Late Cretaceous formations of interest in the DHCW are the Lance Formation, Fox Hills Sandstone and Pierre Shale. Deposited during regression of the Late Cretaceous Seaway, the Lance Formation portrays deposition in a highly variable fluvio-deltaic system, while the Fox Hills is dominantly nearshore marine sandstones. (Lisenbee & DeWitt 1993) The Pierre Shale represents offshore marine deposition, with fine grain materials dominating the sequence.

The primary importance of Late Cretaceous units in the DHCW is the potential for storage and recovery of produced water. While the Lance and Fox Hills formations are the deepest practical receiving aquifers in a Class 5C injection permit, the Pierre Shale acts as a substantial groundwater barrier between deeper aquifers and the Lance/Fox Hills with vastly different water qualities.

2.1.5 Soils

2.1.5.1 General

Topography within the DHCW ranges from relatively small areas of nearly level to gently sloping uplands in the upper reaches of the DHCW, to much larger areas of steep, dissected slopes in the mid-to-lower portions. Soils were mapped by the Natural Resources Conservation Service (NRCS) within Campbell County. Johnson County soils have not been mapped by the NRCS. However, the soils of Johnson County were mapped on a reconnaissance level for inclusion in this study. Soils were mapped from aerial photography (scale: four inches per mile) as major complexes. Soil mapping units developed by the NRCS for southern Campbell County were utilized. Soil units were field checked only along major roads and trails, thus the Johnson County soils information should be considered as preliminary in nature.

Soils within the DHCW are distributed according to primary differences in parent material (both residual and depositional), elevation, moisture, and topographic slope and position. Baseline soils information was obtained from existing Order 3 NRCS soils mapping from South Campbell County, non-published but available in file format from the NRCS office in Gillette, Wyoming. NRCS soil mapping for South Campbell County is available in digital format as USDA NRCS Soil Survey Geographic (SSURGO) data. The Johnson County soils information was digitized and merged with the Campbell County GIS mapping. A depiction of the soils within the DHCW is presented in Figure 2.1.6.

2.1.5.2 General Soil Characteristics

The DHCW is a major tributary of the Powder River, which occupies a structural basin bounded on the west by the Big Horn Mountains and on the east by the Black Hills. The Wasatch Formation of the Eocene Age is exposed over the entire drainage basin and has a distinct impact as parent material on the subsequent development of soils and their distribution. Textures in the Wasatch are variable, and include sandstone, siltstone, mudstone, and conglomerate.

Within the mapped portion of the drainage, soils are primarily included in the following major soil orders: Alfisols; Aridisols; Entisols; Inceptisols; and Mollisols. These soils formed under a dry, cool climate with predominant spring moisture. Soils generally have low organic matter that is limited to the upper horizon; higher values may be found in their drainage bottoms where vegetation productivity and moisture conditions are higher. Soils are formed from residuum on tertiary bedrock-controlled uplands, and in quaternary alluvium and colluvium along stream channels and toeslopes. Principal parent materials of soils in the project area are shales, siltstones, sandstones, and mixed alluvium.

2.1.5.3 Distribution of Mapped Units

NRCS Order 3 (available in southern Campbell County) and the Johnson County reconnaissance soil mapping are considered a gross scale approximation of the soils within the DHCW. On a smaller scale, inclusions of secondary soil types in the larger map units are likely. Soils within a drainage bottom are especially variable due to the dynamic nature of the processes that deposited the parent material or alluvium. Deposition will vary by size of the flow event and intensity of channel meandering over time. Table 2.1.4 summarizes each map unit by total acres and percentage of area. Soils representing less than one half of one percent of the study area (less than 500 acres total area) are listed in the table as "miscellaneous" soils and are not detailed here. Detailed map unit descriptions, including miscellaneous soils, are presented in Appendix 1.

Table 2.1.4
Soil Mapping Units and Areas Within the DHCW

Map Unit	Acres	%		Map Unit	Acres	%
217	30,074	30.6		146	1,065	1.1
233	20,230	20.6		116	947	1.0
147	5,918	6.0		148	945	1.0
122	3,428	3.5		135	882	0.9
153	3,337	3.4		188	881	0.9
215	2,845	2.9		165	864	0.9
158	2,258	2.3		201	839	0.9
117	2,154	2.2		213	625	0.6
216	1,714	1.7		170	615	0.6
250	1,445	1.5		171	579	0.6
114	1,418	1.4		211	573	0.6
127	1,227	1.2		166	524	0.5
157	1,230	1.3		142	493	0.5
206	1,176	1.2		Misc.	10,074	10.2
				Total	**98,360**	**100.0**

While the DHCW contains over 90 soil map units, including variances of similar units, 27 map units comprise approximately 90 percent of the drainage basin. Approximately 10 percent of the mapped area was comprised of the remaining soil units and are considered minor soils for this discussion. Two soil units dominate the DHCW: Unit 217, Theedle-Shingle loams, 0 to 30% slopes and Unit 233, Ustic Torriorthents, gullied. Unit 233 comprises 20 percent of the DHCW and is located within the narrow drainages of the headwaters. These are young, highly erosive, and severely gullied soils. The soil series inclusion in this map unit that comprises the actual drainage bottom is Haverdad, which comprises less than 20% of the overall map unit. Less material has been deposited in these upper drainage bottoms; therefore, terracing and meandering of stream channels are not evident. This unit is not suited for land application, overland flow, or direct discharge of CBM waters due to its highly erosive, steep nature.

Unit 217 comprises 30 percent of the DHCW and is present on the summits, ridges, and shoulders above the gullied Ustic Torriorthent unit. Soil textures are generally fine loamy, and the depth to bedrock on these soils ranges from 10 to 40 inches. While this soil may comprise significant acreage, some of which could be considered for CBM management alternatives such as land application, the depth to bedrock and the steepness of the area may prohibit those activities.

Some hillsides in the drainage are dominated by Unit 147, Forkwood-Cushman loams, 6 to 15% slopes and Unit 122, Cushman-Cambria Loams, 6 to 15% slopes. Unit 147 comprises 6 percent (approximately 6,000) acres in the drainage, and Unit 122 comprises 3.5 percent. While these soils comprise significant acreage in the drainage, the steep slopes may prohibit their use for irrigation water management alternatives.

The main map unit within the Dead Horse Creek channel itself is Unit 153, Haverdad-Kishona Association, developed on 0-6% slopes. Vegetation distribution varies with microtopography. The channel itself may be vegetated with various hydrophytic species or consist of bare areas resulting from late-season pooling. Areas adjacent to the channel will consist of species tolerant of inundation cycles and/or salt deposition. This tolerance will likely decrease as one moves away from the channel. Salt deposition will also likely move deeper into the soil profile as one moves away from the channel. Secondary terraces within these developed channels are more numerous downstream, toward the confluence with the Powder River. Pockets of high saline/sodic soils are interspersed throughout the landscape.

Vegetation descriptions of these units are described in Section 2.1.6 – Vegetation.

2.1.5.4 <u>Soil Texture and Slope</u>

A large portion of soils in the DHCW was derived from siltstones and shales, which produce medium-to-fine textured soils. Soil textures primarily consist of clay loams, silt loams, and silty clay loams, and occur in all topographic settings. The more erodible, silty material found within subdrainages generally forms the alluvial parent material from which soils are derived in those locations. Soils within actively changing areas, such as drainages or steep slopes, have little or no soil development, and paralithic contact is generally near the surface. Slopes within the study area are generally steep (10-40%) within the lower reaches, and level to undulating (0-10%) in the upper reaches of the watershed.

Decisions on possibly providing irrigation water on these soils in conjunction with CBM water management alternatives will be based largely on the soil texture, i.e., percentage of sand, silt, clay, and coarse fragments. Examination of soil textural families and the distribution of those textural families within the basin will be important to understanding water management alternatives for these soils. Soil textural families and the number of major soil series representing each family within the mapped portion of the study area are listed in Table 2.1.5.

Table 2.1.5
DHCW Soil Textural Family Distribution

Textural Family	Acres	%
Sandy	2,521	2.6
Coarse Loamy	18,585	18.9
Fine Loamy	73,128	74.3
Fine Silty	711	0.7
Fine	3,132	3.2
Very Fine	176	0.2
Water/Misc.	107	0.1
Total	**98,360**	**100.0**

As can be seen, almost 80 percent of the DHCW is dominated by fine textured soils, including fine loamy, fine silty, fine, and very fine textures. Only 20 percent of the basin is comprised of soils dominated by coarse loamy and sandy soils.

2.1.5.5 Soil Depth

Soils are deep (greater than 40 inches) on alluvial fans, basins and valley alluvium. Shallow soils (less than 20 inches) occur on planes underlain by siltstone, shale and sandstone bedrock, as well as in areas with steeper topography such as ravines. Moderately deep soils are those between 20 and 40 inches in depth; these soils generally lie on residual upland planes and relatively gentle sideslopes. As noted previously, much of the basin is dominated by soils with limitations on soil depth.

The effective rooting depth, or the ability of the roots to penetrate the soil profile, approximates the total soil depth or is slightly shallower. The depth to bedrock, however, presents some chemical and physical limitations in the suitability of soil map units for reclamation. Since slopes are steep and resulting soil debts are shallow, limited topsoil is available for salvage and use for reclamation of roads, pipelines, drill pads, etc. Soil depth also significantly governs the ability of the soil to store large volumes of water, and also it alters the ability to leach salts from the root zone as necessary.

2.1.5.6 Soil Permeability

The majority of the soils within the DHCW have moderate-to-low permeability. Areas with sandy soil textures, however, have much higher permeability. Soils with clayey textures have moderately low to low permeability. Soil crusting at the surface also reduces infiltration rates. Areas of inherently high salts and/or sodium generally contain visual panspots or slickspots, which are sealed from any surface infiltration. Such areas will appear as white, smooth areas that are devoid of vegetation. As noted in Section 2.1.5.4, only 20 percent of the soils in the basin can be expected to have moderate to high permeability (sandy and coarse loamy soils). The remaining 80 percent can be expected to have permeabilities ranging from moderately low to very low.

Bedrock underlying the soils is generally fractured, which makes it highly permeable in some areas. Limited areas may exist, however, that have impermeable shale layers underlying the soil material. Soils with a high clay content (especially smetitic clays) are subject to cracking upon wetting and drying. Soils adjacent to major drainages tend to be stratified with repeating layers of finer and coarser soil material, which allows for differential lateral flow within these layers.

2.1.5.7 Soil Productivity and Salinity/Sodicity

Soil productivity is naturally low for a portion of the DHCW due to steep slopes and associated shallow soil depths. As with most areas in this region, soils typically have adequate potassium for plant growth, while nitrogen and phosphorus may be limiting plant growth. Effective precipitation is the chief controlling factor of productivity. Lower precipitation produces less vegetative cover and, consequently, less organic matter for the soil.

Natural areas of salinity/sodium will occur where parent material with higher levels of salinity/ sodium is present. Water has promoted percolation of such salts into the profile over time, or natural and man-made dams or diversions have allowed ponding of water at or near the surface. Soil crusting due to inherit or induced sodium in the soil will affect soil productivity by reducing infiltration rates. Salinity will affect osmotic potential in soils and eventual water uptake by plant roots, which would make available precipitation less effective. Of the major soils series found within the mapped portion of the study area, three are classified as Natriagids and two as Calciargids, which would indicate increased levels of sodium and calcium carbonate, respectively. In addition, the approximate 26% of the mapped portion of the study area that contains clayey or fine textured soils also likely contains lime and/or sodium at depth in the profile, due to low permeability and deposition of soluble salts. The Arvada, thick-surface-Arvada-Slickspots complex (three separate soils) is found in scattered pockets near the North Prong of Dead Horse Creek; the Arvada soil series is in a Natriargid which generally contain the nitric or sodium affected horizons. Additional series that may contain high salinity/sodium at depth are Emigha, Moorhead and Leiter.

2.1.5.8 Available Water Capacity

Shallow soils have a lower total water-holding capacity than deeper soils due to lack of depth and ultimate volume. In areas where shale (especially impervious shale) is the underlying bedrock, water will percolate through the soil profile and move laterally when it hits the impervious layer. From a physical standpoint, medium-textured soils have a higher available water capacity than either heavy clay soils or coarse-textured soils.

Total water holding capacity of the basin soils is high due to the high clay content of the soils. However, the average available water holding capacity; i.e., water available for plant uptake for the soils in the project area, is low to moderate because soil clays tend to hold water tightly, and plants cannot effectively extract much of the water.

2.1.5.9 Seasonal High Water Table

In general, the shallow water table within the study area is likely greater than six feet below the soil surface, especially in upland areas. Narrow drainages, flood plains, alluvial terraces, seep areas, stream beds, and bottom lands are likely areas that will contain varying seasonal water tables, depending upon the overall moisture level in a specific year. Likely salt and/or sodium deposition within these soils will also vary based upon these fluctuating levels. Flooding is rare, typically brief, and generally associated with spring runoff and summer storm events.

2.1.6 Vegetation

Range (Ecological) site delineations and other information contained herein are obtained from NRCS information. While the Bureau of Land Management (BLM) and Wyoming Game and Fish Department (WGFD) vegetation maps and reports were reviewed, they were deemed to be too generic and general to be of use in this report.

Range (Ecological) sites for DHCW, WHCW and SHCW are summarized in the individual categories and acreage compositions of Table 2.1.6. For interpretive purposes, all range sites were grouped into categories, resulting in similar range characteristics. Combination range sites are a result of multiple soil and range site complexes. Range sites are defined mainly by soil surface textural classes, but have been further delineated due to precipitation regime. Many sites fall in the 10-14 inch precipitation Northern Plains (np) category, with the remainder of sites present in the 15-17 np category. Some sites are modified by soil chemistry, such as "Saline upland", and others by topography, such as "Lowland". All range sites have been categorized based on productivity. Gullied areas for soil types such as Ustic Torrirothents have not been assigned a range site because of the variability of plant species and soil textural families. These sites are simply listed as "unspecified". All other soil types have a range site determination with a corresponding characteristic plant community with percent composition.

NRCS range site information for Campbell, Sheridan, and Johnson County is provided in Appendix 1. The Ecological Vegetation sites for DHCW are presented by soil mapping unit in the legend shown on Figure 2.1.6.

Native vegetation in the DHCW is dominated by grasses, with a smaller component of shrubs. Site specific range information for a particular area of interest can be found by locating that soil map unit on the figure. The uplands of the DHCW are predominantly Loamy-Shallow Loamy range sites, with 42 of the soil associations being in these categories. These ecological sites comprise 58% of the drainage. All of the Loamy-Shallow Loamy range sites are typically composed of needle and thread (*Stipa comata*), western wheatgrass (*Pascopyrum smithii*), green needlegrass (*Stipa viridula*), blue grama (*Bouteloua gracilis*), and Big sagebrush (*Artemesia tridentata*). A typical Loamy site in the 15-17 np zone will have an additional component of big bluestem (*Andropogon gerardii*) and Sandberg's bluegrass (Poa

Table 2.1.6
Ecological (Range) Site Summary

	DHCW				WHCW				SHCW		
Eco. Site	# Soil Units	Acres	% Area	Eco. Site	# Soil Units	Acres	% Area	Eco. Site	# Soil Units	Acres	% Area
	LOAMS				LOAMS				LOAMS		
L10	21	20641		L10/L15	48	40499		L10/L15	40	17864	
L15	14	4221		SL10/SL15	13	58307		L10/SL10 &	4	1427	
SL10	1	561		SL10/VS	1	94		L15/SL15			
L10/SL10	4	31395		**Sub-total**	**62**	**98900**	**42.3**	SL10/SL15	3	5467	
L15/SL15	1	260						**Sub_total**	**47**	**24758**	**40.1**
SL10/VS	1	58			SANDS						
Sub-total	**42**	**57136**	**58.1**	S10/S15	23	10236			SANDS		
				L10/S10	1	628		S10/S15	18	5745	
	SANDS			SL10/SS10	7	8036		S10/SS10	1	27	
L10/S10	1	277		S10/SS10	8	4889		**Sub_total**	**19**	**5772**	**9.4**
S10	8	4160		& S15/SS15							
S15	6	1460		SA10 &	4	1195			CLAYS		
SA10	1	863		S10/SA10				C10/C15	13	5240	
S10/SA10	3	1195		**Sub-total**	**43**	**24984**	**10.7**	C10/SL10 &	3	5537	
S10/SS10	4	1028						C15/SL15			
S15/SS15	1	340			CLAYS			SC10/SL10 &	4	6465	
SL10/SS10	1	298		C10/C15	15	20406		SL15/SC15			
Sub-total	**25**	**9622**	**9.8**	C10/SC10 &	5	4702		SC10/VS	1	42	
				C15/SC15				SL15/C15	1	190	
	CLAYS			SL15/SC15	2	23718		CO15	1	13	
C10	7	489		L15/C15	2	207		C10/L10	1	1440	
C15	2	93		SC10	3	12635		**Sub_total**	**24**	**18927**	**30.7**
C10/SL10	2	212		C10/L10	2	11283					
L10/C10	3	464		CO10/CO15	3	687			OTHER		
SL10/C10	1	823		C15/SL15	1	762		SA10/SA15	**2**	**134**	**0.2**
SL10/SC10	1	1153		**Sub_total**	**33**	**74400**	**31.8**				
Sub-total	**16**	**3234**	**3.3**					LL10/LL15	**4**	**1563**	**2.5**
	OTHER				OTHER			PP/LB	**2**	**3204**	**5.2**
L10/SU10	**2**	**590**	**0.6**	SA10/SA15	**4**	**3046**	**1.3**				
								WSG	**2**	**2908**	**4.7**
L10/LL10	**1**	**3272**	**3.3**	LL10/LL15	**7**	**5825**	**2.5**				
								Badlands	**6**	**3183**	**5.2**
Ustic Torriorthent	**1**	**20021**	**20.4**	Ustic Torriorthent	**1**	**5615**	**2.4**				
								Misc.	**8**	**1217**	**2.0**
Water	**1**	**17**	**0**	Misc.	**22**	**10579**	**4.5**				
								TOTAL		**61,666**	**100.0**
Misc.	**22**	**4469**	**4.5**	Not mapped	**1**	**10311**	**4.4**				
TOTAL		**98,360**	**100.0**	**TOTAL**		**233,660**	**100.0**				

LEGEND:

L10	Loamy 10-14" np	SS10	Shallow-sandy 10-14" np	SU10	Saline upland 10-14" np
L15	Loamy 15-17" np	SS15	Shallow-sandy 15-17" np	LL10	Lowland 10-14" np
SL10	Shallow-loamy 10-14" np	SA10	Saline 10-14"np	CO15	Clayey Overflow 15-17" np
SL15	Shallow-loamy 15-17" np	C10	Clayey 10-14" np	PPLB	Ponderosa Pine/L. Bluestem
VS	Very shallow	C15	Clayey 15-17" np	WSG	Woodland suitability group
S10	Sandy 10-14" np	SC10	Shallow-clayey 10-14" np	Misc.	Miscellaneous
S15	Sandy 15-17" np	SC15	Shallow clayey 15-17"np		

sandbergii). Typical Shallow Loamy sites have a significant amount of bluebunch wheatgrass *(Pseudoroegneria spicata)*, plus a minor component of little bluestem (*Schizachyrium scoparium*) and threadleaf sedge (*Carex filifolia*). As with all of the range sites, specific productivity and percent composition of individual species can be found in Appendix 1.

Sandy-Sands-Shallow Sandy range sites comprise considerably less area in the DHCW than the Loams. These combinations of Sandy-Sands sites comprise 25 soil associations representing 10% of the drainage basin. The predominant species present in all of these sites are needleandthread, prairie sandreed (*Calamovilfa longifolia*), Indian ricegrass (*Oryzopsis hymenoides*), Silver sagebrush (*Artemesia cana*), and threadleaf sedge. Typical Sandy (10-14 np) sites will have an additional component of little bluestem, western wheatgrass and blue grama. Typical Sandy (15-17 np) sites lack blue grama. Typical Sands (10-14 np) have a significant component of sand bluestem (*Andropogon hallii*) and lack little bluestem, western wheatgrass and blue grama. The Shallow Sandy (10-14 np) sites will typically have a component of bluebunch wheatgrass.

Clayey-Shallow Clayey range sites comprise 16 soil types and only 3 percent of the DHCW basin. The typically predominant species are green needlegrass, western wheatgrass, blue grama, and Big sagebrush. A typical Clayey (10-14 np) site may contain Skyline bluegrass (*Poa epilis*). Clayey (15-17 np) has a component of Big bluestem and sideoats grama (*Bouteloua curtipendula*). The Shallow Clayey (10-14 np) site typically has bluebunch wheatgrass.

The drainage bottoms of the major prongs of Dead Horse Creek are classified in a Loamy (10-14 np) and Lowland (10-14 np) unit. This unit comprises only 3270 acres, or 3 percent, of the basin. The Kishona soil series (loamy) faction of this complex consists of green needlegrass, needleandthread, western wheatgrass, blue grama, Cusick's bluegrass (*Poa cusickii*), and Big sagebrush. The Haverdad soil series (lowland) faction of this complex consists of green needlegrass, cottonwood (*Populus deltoides*), needleandthread, slender wheatgrass (*Elymus trachycaulus*), western wheatgrass, Sandberg's bluegrass, and snowberry (*Symphoricarpos occidentalis*).

One significant soil map unit, Unit 217 – Ustic Torriorthent, gullied, comprises approximately 20 percent of the basin. This unit is highly erosive and gullied with variable soil textures and vegetation communities. Because of this, the ecological site for Unit 217 is listed as "unspecified". Site specific field investigations would be necessary to delineate vegetation communities on this unit.

The other range sites of note are the Loamy (10-14 np) and Saline upland (10-14 np) units. These range sites (Mapping Units 102 and 142) are present in the drainage bottom of the upper reaches of the main branch of Dead Horse Creek and comprise less than one percent of the basin. The Emigha, Sodic faction of unit 142 complex consists of Gardner's saltbush (*Atriplex gardnerii*), Inland saltgrass (*Distichlis stricta*), Indian ricegrass, Alkali sacaton (*Sporobolus airoides*), western wheatgrass, bottlebrush squirreltail (*Elymus elymoides*) and greasewood (*Sarcobatus vermiculatus*). The Arvada unit (loamy, thick surface) consists of needleandthread, western wheatgrass, green needlegrass, blue grama, Cusick's bluegrass and big sagebrush.

Range sites with a combination of Loamy-Sandy-Clayey complexes will have a combination of species consistent with their respective unit. The number of these units is relatively small: nine associations. Range (ecological) units described above are general information and should be used as a starting point in a baseline categorization of a site. Detailed site-specific soil and vegetation data would need to be obtained prior to land application even being considered for implementation.

2.1.7 Surface Water

2.1.7.1 Surface Water Hydrology

As stated previously, Dead Horse Creek discharges to the Powder River approximately two miles downstream of the I-90 crossing of the Powder River. The I-90 rest area between Buffalo and Gillette is located at this crossing. The DHCW extends from the confluence with the Powder River, about 24 miles east/southeast, to within approximately 3/4 miles of Wyoming State Highway 50 southwest of Gillette.

The majority of the DHCW lies within the western edge of Campbell County, but discharges to the Powder River within the far easterly part of Johnson County.

2.1.7.2 Surface Water Quantity

Dead Horse Creek appears to be an intermittent stream as classified by WDEQ; i.e., it is a stream that is below the local water table for some part of the year, but is not a perennial stream. Dead Horse Creek is a 4th order channel using the method outlined by Horton, where 1st order channels are unbranched tributaries, 2nd order receive 1st order, etc.

Flow that currently occurs within the DHCW is produced by snowmelt and precipitation runoff events. USGS Gaging Station #06313700 is located immediately upstream of the Dead Horse Creek I-90 crossing at the westerly end of the watershed. Data collected from this station from October 1971 to October 1990 confirms the ephemeral nature of Dead Horse Creek, consistently recording no identifiable base flow in the creek's channel. Data collection from this station was discontinued prior to the 1991 water year, and data was not again collected until April 2000. For approximately two years, USGS operated this gaging station under contract with the U.S. Bureau of Land Management (BLM). However, this operations contract was terminated in April 2002, and data is once again not being collected.

Dead Horse Creek's mean daily flow from October, 1971 to September, 1990 is shown in Figure 2.1.7.

Flow events on Dead Horse Creek occur primarily between the months of March and September. Daily flows in early spring are typically small (less than 50 cubic feet per second, or cfs) and are likely associated with snowmelt and spring runoff. The larger daily flows occur mainly in the summer months and are generally produced by short-duration, high-intensity thunderstorms typical of this portion of the PRB. A frequency distribution curve for Dead Horse Creek has been developed showing the expected frequency of particular storm events, and it is shown in Figure 2.1.8.

Based upon the USGS gaging station data, the average number of no-flow days over the 19-year period from 1971 to 1990 is 195.4 days/year as presented in Table 2.1.7; i.e., Dead Horse Creek historically exhibits no flow at the confluence with the Powder River approximately 54 % of the time. The period of flow is extended beyond that which would be expected by simple runoff alone and suggests a storage and release component which implies that the stream is intermittent.

Table 2.1.7
Average Number of No-flow Days in Dead Horse Creek at USGS #06313700 Gaging Station

Month	Average # of no flow days/month over 19-year period of record 1971 - 1990
January	23.6
February	15.5
March	7.5
April	7.3
May	4.3
June	9.5
July	15.3
August	19.3
September	19.9
October	18.8
November	15.1
December	20.3
Total (days/year)	**195.4**

Precipitation frequency, depth, duration, and recurrence for the DHCW can be found in the *Precipitation Frequency Atlas of the Western United States* prepared by the National Oceanic and Atmospheric Administration (NOAA). (NOAA 1973) Precipitation amounts for a six-hour duration event for various recurrence intervals for the DHCW can be found in the NOAA atlas. (A six-hour event most closely approximates the short duration associated with thunderstorms in the PRB.) Precipitation isopleths presented in the NOAA atlas show that rainfall depths can be expected to increase west to east across the DHCW. Precipitation amounts for typical event occurrences are as follows:

Event	Precipitation Amount (west to east)
2-yr, 6-hr event	0.9 inches to 1.3 inches
5-yr, 6-hr event	1.3 inches to 1.6 inches
10-yr, 6-hr event	1.6 inches to 2.0 inches
25-yr, 6-hr event	2.0 inches to 2.4 inches
50-yr, 6-hr event	2.2 inches to 2.8 inches
100-yr, 6-hr event	2.4 inches to 3.2 inches

It is unlikely that isolated thunderstorms produce a uniform rainfall depth over the entire DHCW. Instead, the typical high-intensity summer thunderstorms can be expected to contribute rainfall to a smaller area, affecting only a portion of the DHCW.

A perspective of expected runoff flow volumes from precipitation events can be gained from the USGS data. For instance, estimates of the runoff flows observed in Dead Horse Creek on a two- year recurrence were made from Figures 2.1.7 and 2.1.8. The two-year recurrence flow can be assumed to be the least flow observed to occur every two years, with the least flow over the period of record being five cfs in 1988 (See Figure 2.1.7). However, a two-year storm does not necessarily have to occur every two years, and it may occur more or less often (averaging two-year recurrence). Consequently, a frequency distribution of the entire data set provides a better estimation tool than a simple biannual review.

Within the 19 years of record, the two-year recurrence is expected to have occurred nine or ten times. As can be seen in Figure 2.1.8, the largest flow occurring with ten or more occurrences over the 19-year period is approximately 45 cfs. The trend line developed and shown in this figure indicates that the two-year recurrence flow may be as high as 80 cfs. The estimated two-year recurrence flow in Dead Horse Creek is therefore estimated to be somewhere between 45 and 80 cfs. This estimate is based upon the limited amount of data available, yet provides some insight into the mean daily flow corresponding to a two-year event in Dead Horse Creek.

Using the runoff modeling computer program SEDCAD 4, an estimated Runoff Curve Number (RCN) of 79 for the DHCW (RCN is an indication of the runoff potential of an area, 79 is within the typical range for native lands in the PRB). Assuming a 2-yr, 6-hr event precipitation of 1.1 inches across the entire DHCW, the mean flow for such an event over a 24-hour period was determined to be 230 cfs. This is 150-185 cfs greater than that which was estimated above from the 19-year monitoring period at the USGS gaging station. The difference in modeled and actual flow results can likely be attributed to precipitation-induced flow abstractions such as infiltration, transpiration, impoundments, diversions/spreader dikes, etc., as well as the likelihood that the storm does not occur across the entire DHCW.

Some flow restriction and capture are expected within the DHCW during a storm event as stormwater runoff is retained in the numerous stock water ponds and impoundments in the basin. Such retention may recharge the shallow alluvium where present. Several areas along Dead Horse Creek contain potholes or scour holes, which have been observed to hold water during portions of the year. Such potholes have been observed in similar watersheds and are created in areas with sandy surface soils that are scoured away during large stormwater runoff events by the high flow velocities and currents. As the events subside, the scoured-out potholes remain and retain water. If the surrounding soils are transmissive, these potholes may also serve as points of recharge to the alluvial aquifer within these soils. No evaluation of the potholes or the soils in their vicinity has been conducted to determine if alluvial aquifers exist in the areas adjacent to these potholes. The potholes are distributed throughout the drainage basin.

Several areas of potential subirrigation, as well as springs, have been observed along Dead Horse Creek and the North and Middle Prongs of Dead Horse Creek. These springs are the tie to the apparent intermittent flow nature of portions of Dead Horse Creek. While the presence of these features indicates the potential for an alluvial aquifer within the Dead Horse Creek flood plain, no such continual aquifer along the valley has yet been identified. If an alluvial aquifer does in fact exist, it appears to be discontinuous and in most areas must have a water table elevation generally lower than the channel bottom to preclude a persistent base flow component in the channel.

2.1.7.3 Surface Water Quality

Very little background or baseline surface water quality data exists for Dead Horse Creek. The USGS, BLM and other agencies have taken samples of snowmelt and precipitation runoff flows opportunistically since the mid-1970's. Table 2.1.8 summarizes the water quality data available to date from these agencies. The data includes up to nine major sample suites that were run on these surface water samples, along with analyses for pH and EC.

Concentrations of various constituents shown in Table 2.1.8 vary widely, with the largest differences noted between spring events and summer thunderstorm runoff. EC numbers range from 952 to 8,000 μmhos/cm, and average 3,488 μmhos/cm. Total Dissolved Solids (TDS) values (calculated from EC for most samples) range from 618 to 5,980 mg/l, with an average of 2,432 mg/l. The dominant anionic species, sulfate (SO_4), ranged from a low of 355 mg/l to 3,480 mg/l, with an average of 1,613 mg/l, while the dominant cation, calcium (Ca), ranged from 82.9 to 520 mg/l and averaged 342.4 mg/l.

Figure 2.1.9 portrays the surface water quality values listed on Table 2.1.8 in graphical form via use of a trilinear diagram. The data and corresponding diagram show that Dead Horse Creek surface water is a strongly calcium sulfate composition. One exception is the surface water sample collected by the BLM on April 12, 2000, which shows the water quality to be more sodium sulfate/sodium carbonate based. In most cases, there is bicarbonate composition in the surface water.

The data in Table 2.1.8 includes data collected by EnTech's subconsultant Environmental Design Engineering (EDE) at the USGS Station #06313700 on Dead Horse Creek during a thunderstorm event on July 23rd and 24th, 2001. During this event, EDE also attempted to identify the change of water quality with time during this significant runoff event. This attempt was performed via use of an automatic pump sampler, which collected a total of 24 water samples. Flow data collected by USGS at the station for this event indicates that the samples were collected during the rising limb of a storm that eventually peaked at approximately 231 cfs.

The water samples collected by EDE with the automatic pump sampler were all analyzed for both pH and EC. This pH and EC sampling was in addition to the samples upon which more extensive testing was conducted as portrayed in Table 2.1.8. Figure 2.1.10 portrays results from the pH and EC analyses. As can be seen, the pH values are observed to be moderately lower than previous sampling events performed by the USGS and the BLM. EC values range from a low of 832 μmhos/cm to a high of 2,110 μmhos/cm, which are considerably lower than for those collected by the USGS and BLM during other periods.

Table 2.1.8
DHCW Surface Water Quality Data Summary

Sample ID	USGS 8/10/76	USGS 4/10/98	BLM 4/30/93	BLM 4/12/00	BLM 4/12/00*	DH-1 7/23/01	DH-12 7/23/01	DH-21 7/23/01	DH 7/16/01**
Discharge (cfs)	.76	.04	N/A	N/A	N/A	N/A	231	N/A	.01
pH (s.u.)	8	7.8	8.3	8.12	8.3	6.79	6.84	6.79	8.3
EC (umhos/cm)	2400	5020	4431	5980	3210	1670	2060	952	1400
HCO3 mg/l	66.4	N/A	327	526	1002	175	154	187	100
Ca mg/l	400	520	19.1	469	82.9	330	396	182	224
Mg mg/l	95	280	196	373	68.5	40	54.9	21.2	42.1
Na mg/l	90	590	455	636	565	31.6	50.8	24	55.1
SAR	1.1	5.2	4.43	5.32	11.12	.44	.63	.45	.89
K mg/l	8.6	19	N/A	15.5	9.1	13.3	14.5	11.4	12.9
Cl mg/l	4	21	19.1	31.3	N/A	N/A	N/A	N/A	N/A
SO4 mg/l	1400	3000	2551	3480	884	864	1240	355	739
TDS mg/l		3263	2880	5890	2087	1086	1339	619	910

*Note: Sample taken at Buffalo Cut-Across during same event
**Note: Grab sample taken during low flow at Johnson County Bridge

Water quality data available on Dead Horse Creek provides a basis for mass balance calculations to compare existing surface water quality and CBM discharge water quality. Establishing dilution characteristics of natural runoff events when mixed with CBM water may prove valuable in evaluating water management techniques.

Two observations can be made from the surface water quality sampling results from Dead Horse Creek.

- While noticeable differences between spring snowmelt runoff and summer thunderstorm runoff exist, water quality over the course of a single event can be variable.
- With few exceptions, the concentrations of parameters within the surface water quality sample suites taken to date generally fall within the limits for the designated purposes of irrigation and livestock/wildlife watering as defined by WDEQ. (WDEQ 1980)

2.1.7.4 Channel Structure and Morphology

Listed below are geomorphological facts concerning the DHCW.

- The average basin length is 22.4 miles, and the average width is 9.3 miles. This gives a basin length-to-width ratio of 2.4.
- The total drainage area of the DHCW is approximately 154 square miles.
- The maximum elevation reached within the DHCW is 5,184 feet above mean sea level (at the southeast corner), and the minimum elevation at the confluence of Dead Horse Creek and the Powder River is 3,920 feet. This results in a total drainage basin relief of 1,264 feet, with an average valley slope of approximately 1.0%.
- Approximately 13 miles upstream from the confluence with the Powder River (near where I-90 leaves the Dead Horse Creek valley bottom and proceeds northeasterly to Gillette), Dead Horse Creek splits into two channels. The northernmost of the two stems of Dead Horse Creek at this point is called the North Prong, and the southern branch remains Dead Horse Creek. Approximately 3½ miles further upstream from the confluence of Dead Horse Creek and the North Prong of Dead Horse Creek, it again splits into two channels. The northernmost of these stems is called the Middle Prong, and the southern branch remains Dead Horse Creek. See Figure 2.1.1.
- The average slopes of the channel thalwegs of the North Prong, the Middle Prong, and the upstream portion of Dead Horse Creek (upstream of the confluence with the North Prong) are

0.7%, 0.8%, and 0.6%, respectively. The average slope of the Dead Horse Creek thalweg downstream of the confluence with the North Prong is 0.3%. All of these branches of Dead Horse Creek exhibit a meandering channel within a broader, lesser meandering floodplain, with the largest meanders and widest flood plain (approximately 1,500 feet) occurring from the confluence of Dead Horse Creek and the North Prong to the Powder River.

- Within the lower portions of the Dead Horse Creek flood plain, the channel is vertically or nearly vertically incised, to depths of 10-12 feet and widths of 15-20 feet. This incised channel continues up Dead Horse Creek and the North and Middle Prongs, becoming shallower near the headwaters of the drainages, at which location headcutting to this incision is observed.
- Dead Horse Creek is an actively eroding channel in the advanced stages of base level lowering.
- The overall sinuosity of the portion of the Dead Horse Creek channel thalweg downstream of the confluence with the North Prong is approximately 1.58. The upper three miles of each of the North Prong, Middle Prong, and Dead Horse Creek thalwegs all exhibit little or no meandering, with sinuosities for these channels in these reaches approaching 1.0. Downstream of these reaches to their confluences with Dead Horse Creek, the sinuosities in the North Prong and Middle Prong channels are 1.34 and 1.35, respectively.
- Channel sinuosity downstream of the upper three miles of the Dead Horse Creek channel and upstream of the confluence of Dead Horse Creek with the North Prong is 1.43. The average valley slopes within the lower reach of Dead Horse Creek (downstream of the confluence with the North Prong) and the upper reach of Dead Horse Creek (upstream of the confluence with the North Prong) are 0.5% and 0.8%, respectively.
- The average valley slopes within the North Prong and the Middle Prong are 0.9% and 1.1%, respectively.

2.1.7.5 Surface Water Permits

Figure 2.1.11 portrays (1) locations for points of diversion for adjudicated surface water rights, (2) locations for reservoir permits and (3) a mapping of irrigated lands in the DHCW. Information was obtained from the recently completed Powder/Tongue River Basin Planning Study. (HKM 2001) Almost all of the reservoir permits are for reservoirs for stock water and domestic use.

2.1.8 Groundwater

2.1.8.1 Groundwater Permits

Figure 2.1.11 also depicts locations for stock water, agricultural and domestic wells permitted by the Wyoming State Engineer's Office (WSEO) within the DHCW as of January, 2001. (HKM 2001) It does **not** show WSEO-permitted CBM well locations for either those permitted prior to or subsequent to the January, 2001 date. It is believed that most if not all wells permitted within the watershed since this date have been for CBM production.

2.1.8.2 Groundwater Hydrology

Underlying the DHCW is a number of aquifers. Figure 2.1.12 portrays the generalized stratigraphic column of the PRB, with noted hydrologic properties. The surface geology is composed of partially saturated recent alluvium (up to twenty feet thick in the main channel) and the Eocene-Age Wasatch Formation.

As discussed in the Surface Water Hydrology section, several areas along the main channels of Dead Horse Creek exhibit scour holes containing water, possible springs, and apparently sub-irrigated vegetation. This suggests the possibility of a discontinuous, partially saturated alluvial aquifer along portions of Dead Horse Creek.

The Wasatch Formation is composed of fluvial sands, silts and shales, as well as paludal carbonaceous material. Groundwater in the Wasatch Formation is normally confined in lenticular sandstones, coals and clinker beds, and it is generally local in nature. On the north side of the drainage, clinker (i.e., scoria) beds outcrop, but they have not been observed in the subsurface.

Underlying the Wasatch Formation is the Tongue River Member of the Fort Union Formation. Paleocene in age, the Tongue River Member is thought to have been deposited in a similar environment to the Wasatch. The coal beds containing the CBM are within the Tongue River Member, and from top to bottom are generally stratified as follows:

- Wyodak-Anderson,
- Canyon,
- Cook,
- Wall, and
- Pawnee.

From east to west in the DHCW, the majority of coal beds coalesce into the Big George Coal, which often exhibits artesian type hydraulic pressures. Freshwater-bearing sandstones are above and interbedded with the coal units, whereas fine-grained, confining mudstones may also be found in the Tongue River Member. The general dip in the DHCW is to the west at approximately 1°.

Underlying the Tongue River Member is the Lebo Shale. This confining unit, composed of carbonaceous shales and thin, discontinuous fine-grained sandstones, is a barrier to vertical groundwater movement throughout the PRB. The earliest Tertiary is represented by the Tullock Member of the Fort Union and contains significant groundwater resources in the sandy aspects of the unit.

Cretaceous groundwater is of primary interest for the purposes of injection of CBM waters. Under a Class 5C5 permit issued by the WDEQ, injection into the Wasatch, Fort Union, Lance and Fox Hills can take place. In order to inject into the deeper Mesozoic and Paleozoic era formations, a Class II Underground Injection Control (UIC) permit must be obtained from the WO&GCC. Cretaceous aquifers of importance consist of the Lance Formation, Fox Hills Sandstone and Pierre Shale formations. With sediments derived from the regression of Late Cretaceous seas, the units represent a coarsening upward sequence, thus the fine-grained shales of the Pierre act as a significant barrier (i.e., aquitard) to water contained in the coarser Fox Hills and Lance formations. Water-bearing zones of the Fox Hills and Lance formations are normally found in relatively continuous sections within the lower one-third of the Lance and the majority of the Fox Hills.

2.1.8.3 <u>Groundwater Quantity</u>

Static water level and well yield data available from the WSEO were used to assess groundwater quantity in the DHCW. No data is available on water quantities from the alluvium along the main channel of Dead Horse Creek. Wasatch Formation water quantities vary widely from location to location and between water-bearing units. While generally confined, WSEO records indicate water levels ranging from flowing to 490 feet below land surface (BLS), with an average of 103 feet BLS. Production from domestic and stock wells completed in the Wasatch range from ½ gallons per minute (gpm) to 25 gpm, with a reported average of 12 gpm.

Aquifer characteristics data for the wells completed in the Fort Union Coals is limited. WSEO data indicates minimum depth to water measurements of 137 feet BLS, although reports of flowing artesian conditions in wells completed in the Big George Coal have been documented. Maximum water levels approaching 960 feet BLS were reported to the WSEO, while average levels are approximately 625 feet BLS. WO&GCC data indicated that maximum yields from wells completed in the Big George seam average 41 gpm, and range from 4 to 145 gpm. Data from the same source for the Wyodak coal beds indicates a much lower average maximum of 18 gpm, with a range of 3 to 47 gpm. (WO&GCC 2002)

2.1.8.4 Groundwater Quality

Large variations in groundwater quality can exist between aquifers - and even within similar units – in the DHCW. No water quality data is currently available for the Dead Horse Creek alluvium. Wasatch Formation water quality varies, depending upon distance from recharge zone (both vertically and horizontally), depth and nature of confinement. Where the potential for communication with surface water exists, the water type is likely to be sodium sulfate, while deeper groundwater (i.e., farther from the recharge area, or confined) is a sodium bicarbonate water type. (U.S. Department of Interior, BLM 2002)

Data from the USGS (four wells) indicates both sodium bicarbonate and sodium sulfate water types in the Wasatch. Figure 2.1.9 portrays the water quality for these four Wasatch wells in addition to surface water quality values. Electrical conductivities (EC's) for the Wasatch range from 442 to 1,140 µmhos/cm and average 779, while TDS concentrations range from 263 to 726 mg/l with a mean of 491 mg/l. Sodium, the dominant cation, averaged 178 mg/l and ranged from 100 to 300 mg/l. Sodium adsorption ratios (SAR) values for the four wells averaged 17 with a low of 11 and a high of 25. The sample with a large sulfate component had concentrations of 68 and 330 mg/l.

Water quality data from the Fort Union Formation, though quite variable in terms of general parameter concentrations, also exhibits a sodium bicarbonate water type. This water type indicates extensive sulfate reduction and methanogenesis of the coals.

Table 2.1.9 portrays in tabular form water quality information on several seams from the DHCW. Included within this water quality information is data on water produced from the Big George seam, the Wall/Pawnee seam, as well as on water being discharged under a current NPDES permit within the DHCW. Figure 2.1.9 also shows graphically the water quality from the Big George and Pawnee samples. It is important to note that all of the analyses indicate a sodium bicarbonate water type.

Data from the six water quality samples taken from the Big George seam exhibit fairly consistent water chemistry. EC's for the wells averaged 2,307 µmhos/cm and ranged from a low of 2,150 to 2,710 µmhos/cm. TDS concentrations had a mean of 1,471 mg/l and ranged from 1,360 mg/l to a high of 1,744 mg/l. The dominant cation, sodium, had concentrations from 542 to 669 mg/l and averaged 585 mg/l. SAR values for the samples were very consistent at 19 to 20. The lone sample from the Wall/Pawnee coal in DHCW came from the USGS and indicates better water quality than the samples from the Big George. With an EC of 1,060 µmhos/cm and a TDS concentration of 624 mg/l, the sample has less than half the dissolved constituents than the overlying groundwater from the Big George. The sodium concentration was 190 mg/l, with an SAR of 8 for the Wall/Pawnee sample.

Variations in concentrations of general parameters can be observed throughout the PRB; however, groundwater quality from Fort Union coal beds varies little in overall water type; i.e., being of a sodium bicarbonate nature.

Table 2.1.10 provides a summary of the groundwater quality data analyzed within the DHCW representative of water pumped as a result of CBM activities. The data is compared in the table to current WDEQ discharge standards.

Table 2.1.9
Summary of CBM Water Quality Data Collected in the DHCW

Water Source	Summary Statistics	pH	Cond umhos/cm	TDS mg/l	F mg/l	Cl mg/l	SO4 mg/l	Alkalinity mg/l	NH4 mg/l	Ca mg/l	K mg/l	Mg mg/l	Na mg/l	HCO3 mg/l	Fe mg/l	SAR
Dead Horse Creek NPDES Data	mean	7.76	1846.00	1177.00	1.77	20.17	147.33	958.33	1.60	39.21	9.70	21.13	438.80	1034.00	1.53	17.68
	std dev.	0.49	544.47	381.67	0.39	8.92	226.31	247.59		18.39	1.13	10.87	99.44	308.91	1.53	13.17
	minimum	7.07	964.00	500.00	1.49	8.00	0.99	682.00	1.60	4.40	9.00	3.30	226.00	682.00	0.14	7.08
	maximum	8.21	2610.00	1740.00	2.04	33.50	408.00	1160.00	1.60	67.10	11.00	40.60	535.60	1260.00	3.50	46.90
	# reported results	9	9	8	2	7	3	3	1	7	3	7	7	3	4	7
Dead Horse Creek, Sections 13 & 18 Wells (Big George)	mean	7.49	2307.14	1328.29	4.16	10.29	0.99	1387.86	n/a	28.73	15.10	22.06	584.56	1693.14	0.04	19.97
	std dev.	0.07	189.01	443.57	0.21	0.49	0.00	125.66		4.41	1.58	1.94	41.99	153.27	0.01	0.54
	minimum	7.40	2150.00	360.00	4.00	10.00	0.99	1280.00		26.10	13.30	20.20	542.50	1562.00	0.03	19.10
	maximum	7.60	2710.00	1744.00	4.60	11.00	0.99	1655.00		38.50	18.10	26.10	669.00	2019.00	0.06	20.77
	# reported results	7	7	7	7	7	7	7		7	7	7	7	7	7	7
USGS Anderson Coal	mean	7.33	1273.89	843.89	0.83	17.98	2.19	934.44	2.01	33.50	7.44	15.90	297.78	766.43	0.39	10.98
	std dev.	0.16	494.62	340.14	0.25	18.48	2.71	381.79	0.54	13.03	2.40	6.20	139.56	313.15	0.32	5.34
	minimum	7.10	630.00	410.00	0.42	6.40	0.01	450.00	1.10	14.00	3.90	4.90	140.00	369.09	0.02	6.90
	maximum	7.70	2380.00	1600.00	1.20	64.00	8.60	1810.00	2.70	56.00	14.00	25.00	640.00	1484.56	1.20	24.00
	# reported results	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
USGS Big George Coal	mean	7.60	3020.00	2010.00	n/a	16.00	0.01	2320.00	4.80	9.10	18.00	28.00	780.00	1902.86	2.80	29.00
	std dev.	n/a	n/a	n/a		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	minimum	7.60	3020.00	2010.00		16.00	0.01	2320.00	4.80	9.10	18.00	28.00	780.00	1902.86	2.80	29.00
	maximum	7.60	3020.00	2010.00		16.00	0.01	2320.00	4.80	9.10	18.00	28.00	780.00	1902.86	2.80	29.00
	# reported results	1	1	1		1	1	1	1	1	1	1	1	1	1	1
USGS Canyon Coal	mean	7.45	1493.33	986.67	0.68	8.98	2.98	1105.00	1.98	27.00	6.37	11.53	375.00	906.32	0.63	15.68
	std dev.	0.14	642.67	420.98	0.18	2.74	4.57	465.01	0.71	15.91	1.33	5.33	184.04	381.40	0.39	7.30
	minimum	7.30	570.00	370.00	0.47	5.20	0.16	430.00	1.20	10.00	4.70	4.00	130.00	352.69	0.03	8.80
	maximum	7.60	2320.00	1550.00	0.98	13.00	12.00	1760.00	3.10	52.00	8.30	18.00	610.00	1443.55	1.00	23.00
	# reported results	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
USGS Cook Coal	mean	7.55	2335.00	1635.00	0.74	13.50	4.13	1835.00	3.00	22.00	9.15	13.50	655.00	1505.07	0.68	27.00
	std dev.	0.07	671.75	516.19	0.37	0.71	5.61	601.04	0.57	2.83	2.62	2.12	205.06	492.97	0.18	7.07
	minimum	7.50	1860.00	1270.00	0.48	13.00	0.16	1410.00	2.60	20.00	7.30	12.00	510.00	1156.48	0.55	22.00
	maximum	7.60	2810.00	2000.00	1.00	14.00	8.10	2260.00	3.40	24.00	11.00	15.00	800.00	1853.65	0.80	32.00
	# reported results	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
USGS Fort Union Coal	mean	6.93	1043.33	670.00	1.20	9.83	0.25	746.67	2.53	33.67	11.67	20.00	213.33	612.42	0.59	7.17
	std dev.	0.06	215.02	151.33	0.46	1.04	0.42	179.54	0.55	8.02	2.08	4.58	51.32	147.26	0.19	0.83
	minimum	6.90	860.00	550.00	0.80	9.00	0.01	610.00	2.00	26.00	10.00	16.00	170.00	500.32	0.42	6.50
	maximum	7.00	1280.00	840.00	1.70	11.00	0.73	950.00	3.10	42.00	14.00	25.00	270.00	779.19	0.79	8.10
	# reported results	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
USGS Pawnee Coal	mean	7.50	860.00	535.00	1.06	7.70	1.52	585.00	1.70	17.95	5.95	7.80	200.00	479.82	0.36	10.65
	std dev.	0.14	551.54	374.77	0.49	3.25	2.09	417.19	0.85	17.04	3.04	8.77	127.28	342.18	0.08	0.49
	minimum	7.40	470.00	270.00	0.71	5.40	0.04	290.00	1.10	5.90	3.80	1.60	110.00	237.86	0.30	10.30
	maximum	7.60	1250.00	800.00	1.40	10.00	3.00	880.00	2.30	30.00	8.10	14.00	290.00	721.78	0.42	11.00
	# reported results	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
USGS Wall Coal	mean	7.40	1935.00	1305.00	0.95	15.00	0.69	1480.00	3.15	32.50	11.20	15.35	490.00	1213.90	0.41	21.20
	std dev.	0.14	459.62	346.48	0.64	4.24	0.87	367.70	0.35	24.75	3.96	9.40	197.99	301.58	0.21	15.27
	minimum	7.30	1610.00	1060.00	0.50	12.00	0.07	1220.00	2.90	15.00	8.40	8.70	350.00	1000.64	0.26	10.40
	maximum	7.50	2260.00	1550.00	1.40	18.00	1.30	1740.00	3.40	50.00	14.00	22.00	630.00	1427.15	0.55	32.00
	# of reported results	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
USGS Wyodak Coal	mean	7.08	999.23	650.00	1.08	9.72	2.83	740.00	2.65	37.69	9.18	18.42	202.31	606.95	1.41	6.81
	std dev.	0.12	328.24	257.07	0.31	2.05	5.33	315.38	1.02	16.53	2.94	11.17	70.73	258.68	1.45	0.80
	minimum	6.80	640.00	390.00	0.60	6.30	0.73	420.00	1.70	19.00	5.80	8.20	130.00	344.48	0.26	5.70
	maximum	7.30	1660.00	1260.00	1.60	14.00	17.00	1520.00	5.30	69.00	15.00	46.00	360.00	1246.70	4.90	8.20
	# of reported results	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
All Aquifers Summary Statistics	mean	7.37	1696.33	1107.09	1.34	12.11	1.73	1237.11	2.73	26.90	10.45	16.95	422.00	1076.32	0.81	16.50
	std dev.	0.04	183.834872	113.341	0.1564	5.94585	2.24079	152.27602	0.2211	7.339	0.8481	3.37435	66.188	114.8755	0.4573	5.206249
	minimum	6.80	470.00	270.00	0.42	5.20	0.01	290.00	1.10	5.90	3.80	1.60	110.00	237.86	0.02	5.70
	maximum	7.70	3020.00	2010.00	4.60	64.00	17.00	2320.00	5.30	69.00	18.10	46.00	800.00	2019.00	4.90	32.00

NOTE: Bicarbonate values for USGS data calculated from Alkalinity numbers, n/a indicates no data or non-detect

Table 2.1.10
Dead Horse Creek CBM Water Quality[1]
vs. WDEQ Discharge Standards

Parameter	CBM Water Maximum Concentration	CBM Water Mean Concentration (N = 12)	Mean Plus 1 Std. Deviations (Upper 80% Confidence Level)	Mean Plus 2 Std. Deviation (Upper 95% Confidence Level)	WDEQ NPDES Discharge Standard
Conductivity	2710 µmhos/cm	2307 µmhos/cm	2496 µmhos/cm	2685 µmhos/cm	7500 µmhos/cm (stock and wildlife water)
Conductivity	2710 µmhos/cm	2307 µmhos/cm	2496 µmhos/cm	2685 µmhos/cm	2000 µmhos/cm (irrigation)
pH	7.6	7.5	7.55	7.6	6.5 – 8.5
TDS	1744 mg/l	1471 mg/l	1601 mg/l	1731 mg/l	5000 mg/l
Oil & Grease	<1 mg/l	<1 mg/l	<1 mg/l	<1 mg/l	10 mg/l
Radium 226	.333 pCi/L	.238 pCi/L	.300 pCi/L	.362 pCi/L	1 pCi/L
Cl	11 mg/l	10.3 mg/l	10.8 mg/l	11.3 mg/l	46 mg/l
SO_4	<1 mg/l	<1 mg/l	<1 mg/l	<1 mg/l	3,000 mg/l
Ca	38.5 mg/l	28.7 mg/l	33.1 mg/l	37.6 mg/l	N/A
Mg	26.1 mg/l	22.1 mg/l	27.0 mg/l	25.9 mg/l	N/A
Na	669 mg/l	584.6 mg/l	626.5 mg/l	668.5 mg/l	N/A
Fe dissolved [2]	0.058 mg/l	0.036 mg/l	0.047 mg/l	0.057 mg/l	0.2997 mg/l
Mn dissolved [2]	0.162 mg/l	0.047 mg/l	0.098 mg/l	0.149 mg/l	0.629 mg/l
As total [2]	0.0015 mg/l	0.001 mg/l	0.0013 mg/l	0.0017 mg/l	0.007 mg/l
Ba total [2]	1.328 mg/l	0.834 mg/l	1.089 mg/l	1.345 mg/l	1.800 mg/l
SAR	20.7	20.0	20.5	21.1	6.0 irrigation

[1] Note: values from USGS Open File Report (00-372) and Big George Coals in DHCW.
[2] Thomas and Hargett 2002

2.1.9 Erosion Potential

Information on the water erosivity of the surface soils within the mapped portion of the study area was compiled using NRCS information regarding the general map unit/soil series for Campbell and Sheridan Counties. Information on erosivity for Johnson County was inferred from Campbell County NRCS data.

Many areas of subsurface soils are prone to erosion due to the silt content of lower soil horizons. Deeply entrenched cuts in the lower reaches of the Three Horses basins demonstrate the inherent erosion potential within that landscape. Soil erodibility due to water and wind varies with soil texture. Silts and silt loams are most susceptible to water erosion. In contrast, fine sands, loamy sands, and coarse sandy loams are most susceptible to wind erosion.

Water erosion primarily occurs during spring snowmelt and in summer from thunderstorms that cause intensive runoff and flash flooding. Streams in the area that have deep, incised channels will erode continually through the caving of channel banks and through headward erosion of the parent material within drainage bottoms. Upland erosion will occur simultaneously due to sheet and rill erosion. The sparse vegetative cover on steep slopes exposes more soil to raindrop impact.

Most areas are likely undergoing moderate natural rates of erosion. The highest natural rate of geologic erosion by water occurs in areas with naturally low vegetative cover, soil crusting, low organic matter content, and soft shales. In areas high in sodium where clays are disbursed, overall soil particles are more easily detached by wind and water. Areas with greater amounts of vegetative cover and organic matter content and/or lower sodium content have a lower natural rate of erosion by water. In addition, areas with harder rock fragments on or near the surface are less susceptible to erosion by either water or wind. Areas with unstable soils on the surface or at depth are susceptible to slumping, sliding and soil creep.

Within the DHCW study area, soils susceptibility to water erosion is generally moderate in the subsurface topsoil horizon and moderate to severe in the subsoil horizons due to clay content, low permeability and non-cohesive soils, as well as steep slopes. These soils may represent 80 percent of the drainage area. Average runoff potential is moderate to high. Overall wind erosion potential is low to moderate due to the low percentage (20%)of sandy and coarse loamy soils in the basin. (Refer to Section 2.1.5 for further descriptions of the DHCW soils.)

Those soils map units in the DHCW occurring on steep upland topography include: Unit 217 – Theedle-Shingle Loams, 3 to 30% slopes, Unit 233 – Ustic Torriorthents, gullied. These soils have fine loamy, fine silty, and fine textures, and erosion potential is moderate to very high depending on texture, vegetative cover, and slope steepness.

Channel soils are predominantly Unit 153 – Haverdad-Kishona Association, 0 to 6% slopes. These soils have fine loamy and fine silty textures and erosion potential is moderate to high, depending on slope and vegetative cover. These soils comprise approximately 3.5% of the drainage.

Sideslopes, alluvial fans, terraces, and colluvial deposits in the drainage are occupied by Unit 147 – Forkwood-Cushman Loams, 6 to 15% slopes and Unit 122 – Cushman-Cambria loams, 6 to 15% slopes. These soils have coarse loamy surface textures and the erosion potential is low to moderately high.

High saline and/or sodic soils that are susceptible to surface erosion include: Emigha and sodic-Arvada. While erosion potential is high on these soils, they comprise a small percentage of the drainage basin.

While the above discussion describes the dominant soil units in the drainage, numerous soil map units occur, and each soil map unit description located in Appendix 1 should be reviewed to assess erosion potential on each map unit.

2.2 WILD HORSE CREEK

2.2.1 Geography and Topography

The WHCW is located primarily within Campbell and Sheridan Counties, with a very small part (less than 40 acres) also being within Johnson County. Like Dead Horse Creek, Wild Horse Creek also extends upstream from the Powder River in an easterly and southerly direction, with the confluence at the unincorporated town of Arvada, Wyoming. Figure 2.2.1 depicts the watershed boundary and the enclosed 233,600 acres (approximately 365 square miles).

The highest elevation in the watershed is 5,036 feet, located in Section 35, T49N, R74W. The confluence with the Powder River is the lowest point in the watershed, which is in Section 16, T54N, R77W and at elevation 3,640 feet. The total elevation difference is thus approximately 1,400 feet over a horizontal distance of approximately 43 miles (32.6 feet/mile, or 0.6%). This slope is considerably flatter than the DHCW's average slope of 1.0%.

2.2.2 Surface Ownership

Figure 2.1.2 depicts the surface ownership within the WHCW. (U.S. Department of Interior, BLM 2002) The amount of land and percentage of surface ownership among federal, state and private interests in the WHCW is as shown in Table 2.2.1.

Table 2.2.1
Wild Horse Creek Watershed Surface Ownership

Ownership	Area (sq. mi.)	%
Federal	64.8	17.8
State	22.8	6.2
Private	277.4	76.0
Totals	365.0	100.0

2.2.3 Minerals Ownership

Figure 2.1.3 portrays the ownership of federal minerals within the Three Horses watersheds, including within the WCHW. (U.S. Department of Interior, BLM) The amount of land and percentage of minerals ownership among federal and other interests within this watershed is as shown in Table 2.2.2:

Table 2.2.2
Wild Horse Creek Watershed Minerals Ownership

Ownership	Area (sq. mi.)	%
Federal	225.4	61.7
All Other	139.6	38.3
Totals	365.0	100.0

Although not as high of a percentage as with the DHCW, the federal government still constitutes the majority minerals owner within the WHCW.

2.2.4 Geology

Geology of the WHCW is very similar to that of the DHCW. Like the DHCW, the WHCW surface is comprised of Recent or Quaternary alluvium along the main channel and its main tributaries, as well as the Eocene Age Wasatch Formation. Thickness of the alluvium is quite variable, as are the minor colluvial deposits seen in the drainage. The Wasatch, encompassing a wide range of sedimentary facies, covers the majority of the watershed. With alluvial sediments from mudstones through conglomerates, the Wasatch contains minor producing coal beds in the drainage. This production primarily takes place in the Felix Coal which is normally less than 300 feet from the surface. (WO&GCC 2002)

Little coarse sediment has been noted in the Wasatch in the WHCW, with the majority of the unit composed of mudstones and interbedded sands, silts and clays along with thin coal beds. (Seeland 1992; Ellis and others 1999a) Thickness of the Wasatch formation in the WHCW does not exceed 500 feet, although due to very similar lithologies, differentiation between the underlying Fort Union Formation can be quite difficult.

Underlying the Wasatch in the WHCW in a nonconforming manner is the Paleocene Fort Union Formation. Composed of three primary members, the Fort Union Formation contains the majority of the coals associated with both CBM and coal production in the PRB. The Tongue River Member, Lebo Member and Tullock Member portray an earlier phase of erosion and deposition in the basin. The Tongue River Member of the Fort Union, primarily composed of sandstones and thick coal beds, overlies the older members. Active CBM production in the WHCW is occurring in the Smith, Anderson, Canyon, Cook/Werner, Wall and Pawnee coal units. Complexity due to the merging, splitting and pinching out of coals results in varied nomenclature and more localized "upper" and "lower" designations for coal sequences. Thickness of the producing coals in the watershed ranges from approximately 30 feet to more than 100 feet, with typical completions ranging from 35 to 45 feet. (WO&GCC 2002) Underlying the

Tongue River Member in the WHCW is the Lebo Shale and Tullock Member. Composed of dark shales, thin channel sandstones and marginal coal seams, the Lebo Shale easily approaches several thousand feet in thickness. The Tullock Member portrays earliest Paleocene deposition in the PRB, with alluvial sediments from fine-grained sandstones, siltstones and shales with minor, thin coal seams. The general dip of the formations within the WHCW is to the west at approximately 1°.

The majority of these coal seams within the WHCW coalesce into the Big George Coal. Data on the thickness of these coal seams is portrayed in Table 2.2.3. (WO&GCC 2002)

Table 2.2.3
Coal Seam Thickness Summary

Coal Seam	Number of Data Points	Mean Thickness (ft)	Maximum Thickness (ft)	Minimum Thickness (ft)
Smith	9	25.7	35	18
Anderson	259	26	133	8
Canyon	35	18	65	22
Cook	60	38	77	22
Wall/Pawnee	4	52.3	85	40

Representing Late Cretaceous deposition in the area are three primary formations. From stratigraphic top to bottom they include the Lance, Fox Hills, and Pierre Shale. While the Lance and Fox Hills portray deposition during regression of the Late Cretaceous Seaway and its associated fluvio-deltaic systems, the Pierre Shale represents offshore marine deposition dominated by fine grained materials. As mentioned above, these Late Cretaceous formations are the deepest available for a Class 5C5 injection permit for CBM produced water, as the fine grained, confining nature of the Pierre Shale acts as a barrier for the varied water quality types seen in the basin.

2.2.5 Soils

2.2.5.1 General

Topography within the WHCW ranges from relatively small areas of nearly level to gently sloping uplands in the upper reaches of the WHCW, to much larger areas of steep, dissected slopes in the mid-to-lower portions. Stream terraces and floodplains in this drainage are far more prominent than in the DHCW. Soils were mapped by the NRCS within Campbell County and Sheridan County. Johnson County soils representing a very small fraction of the drainage have not been mapped.

Campbell County baseline soils information was obtained from preliminary Order 3 NRCS soils mapping from North Campbell County, including non-published mapping unit descriptions, legends, etc. from the NRCS office in Gillette, Wyoming. None of the mapping or databases for North Campbell County is available in digital format as USDA NRCS Soil Survey Geographic (SSURGO) data. Therefore, all Campbell County WHCW soils were digitized into GIS databases to allow digital production of soil maps. Because Campbell County information is preliminary, a few soil map units did not have correlated map unit descriptions. These soils are identified with four-digit soil unit numbers and are treated as miscellaneous soils in this report.

Sheridan County baseline soils information and maps were obtained from the published 1998 Sheridan County Soil Survey. As with Campbell County, this soils information was not available in digital format, thus all Sheridan County soils in WHCW were digitized into the GIS format. Where possible, Sheridan County soil map units were cross-referenced with Campbell county map units, and similar units were assigned the same map unit number to lessen confusion between counties. Unique Sheridan County units were assigned unique map unit numbers.

Soils maps for the WHCW are presented in this report as Figures 2.2.2 and 2.2.3.

2.2.5.2 General Soil Characteristics

The WHCW is a major tributary of the Powder River, which occupies a structural basin bounded on the west by the Big Horn Mountains and on the east by the Black Hills. The Wasatch Formation of the Eocene Age is exposed over the entire drainage basin and has a distinct impact as parent material on the subsequent development of soils and their distribution. Textures in the Wasatch are variable, and include sandstone, siltstone, mudstone, and conglomerate.

Within the mapped portion of the drainage, soils are primarily included in the following major soil orders: Alfisols; Aridisols; Entisols; Inceptisols; and Mollisols. These soils formed under a dry, cool climate with predominant spring moisture. Soils generally have low organic matter that is limited to the upper horizon; higher values may be found in their drainage bottoms where vegetation productivity and moisture conditions are higher. Soils are formed from residuum on tertiary bedrock-controlled uplands, and in quaternary alluvium and colluvium along stream channels and toeslopes. Principal parent materials of soils in the project area are shales, siltstones, sandstones, and mixed alluvium.

2.2.5.3 Distribution of Mapped Units

The NRCS Order 3 Sheridan County published soil maps and the Campbell County unpublished soil maps are considered a gross scale approximation of the soils within the WHCW. On a smaller scale, inclusions of secondary soil types in the larger map units are likely. Soils within a drainage bottom are especially variable due to the dynamic nature of the processes that deposited the parent material or alluvium. Deposition will vary by size of the flow event and intensity of channel meandering over time. Table 2.2.4 summarizes each map unit by total acres and percentage of area. Soils representing less than one half of one percent of the study area (generally less than 1000 acres total area) are listed in the table as "miscellaneous" soils and are not detailed here. Note that approximately 10,000 acres have not been mapped in WHCW because of access issues. Detailed map unit descriptions, including miscellaneous soils, are presented in Appendix 1.

While the WHCW contains over 140 soil map units, including variances of similar units, 44 map units comprise approximately 80 percent of the drainage basin, and unmapped areas comprise 5 percent. Approximately 15 percent of the mapped area was comprised of the remaining soil units and are considered minor soils for this discussion. Two soil units dominant the WHCW, Unit 225, Ucross-Iwait-Fairburn loams, 3 to 30% slopes and Unit 312, Fairburn,-Samsil- Badlands complex, 25 to 60 percent slopes comprises 15.5 percent and 10 percent of the WHCW, respectively.

Unit 217 is present on summits, ridges, and shoulders above the gullied and dissected badlands complexes described below. Soil textures are generally fine loamy (loams to clay loams) and depth to bedrock ranges from 10 inches to greater than 40 inches. While this soil may comprise significant acreage, some of which could be considered for management options such as land application, the depth to bedrock and the steepness of the area may prohibit those activities.

Unit 312 is present on summits, shoulders, and heavily dissected gullies. Much of the unit is shallow to bedrock, commonly ranging from 10 to 20 inches to bedrock comprised of sandstone and shales. Textures are fine loamy (loams to clay loams). Fifteen percent of this unit is comprised of highly erosive, fine textured badlands, nearly devoid of vegetation. In addition, approximately 5 percent of the drainage is also comprised of Unit 206, Samday-Shingle-Badlands complex, 10 to 45% slopes. This unit is similar to Unit 312 except textures are fine (clay loams to clays) and underlying bedrock is calcareous shale. This unit will not be acceptable for most water management options entailing irrigation methods.

Table 2.2.4
Soil Mapping Units and Areas Within the WHCW

Map Unit	Acres	%		Map Unit	Acres	%
225	36,274	15.5		253	2,212	0.9
312	23,511	10.1		147	2,120	0.9
206	12,281	5.3		261	1,936	0.8
Not mapped	10,953	4.7		138	1,827	0.8
255	10,339	4.4		166	1,797	0.8
216	7,379	3.2		330	1,770	0.8
204	7,362	3.2		227	1,720	0.7
135	6,037	2.6		215	1,671	0.7
233	5,524	2.4		205	1,604	0.7
242	5,061	2.2		268	1,596	0.7
217	4,727	2.0		176	1,528	0.7
239	3,928	1.7		106	1,487	0.6
184	3,638	1.6		203	1,440	0.6
298	3,539	1.5		224	1,358	0.6
183	3,200	1.4		146	1,292	0.6
283	2,996	1.3		167	1,282	0.5
305	2,878	1.2		256	1,271	0.5
250	2,862	1.2		132	1,253	0.5
134	2,847	1.2		103	1,240	0.5
168	2,706	1.2		260	1,230	0.5
229	2,590	1.1		238	1,186	0.5
114	2,478	1.1		236	1,183	0.5
279	2,440	1.0		Misc.	34,047	14.6
				Total	**233,600**	**100.0**

The main map unit within the Wild Horse Creek floodplain and adjacent terraces is Unit 298, Haverdad-Boruff Complex, developed on 0-6% slopes. Textures are variable ranging from sandy to fine loamy depending on depositional environments. Vegetation distribution varies with microtopography. The channel itself may be vegetated with various hydrophytic species or consist of bare areas resulting from late-season pooling. Areas adjacent to the channel will consist of species tolerant of inundation cycles and/or salt deposition. This tolerance will likely decrease as one moves away from the channel. Salt deposition will also likely move deeper into the soil profile as one moves away from the channel. Secondary terraces within these developed channels are common. Pockets of high saline/sodic soils are interspersed throughout the landscape, including adjacent terraces. These soils may be comprised of Absted-slickspots Complex (Unit 252) or the Absted-Arvada-Slickspots Complex (Unit 253).

Alluvial terraces fans adjacent to the Wild Horse floodplain may often consist of Unit 255, Ulm-bidman Complex, 0 to 6% slopes. These soils are relatively flat compared to the adjacent uplands and side areas and are often comprised of clay loam to clay textures. These soils may become important for water management options, particularly for land application. However, the fine textures make land application management difficult.

Vegetation descriptions of these units are described in Section 2.2.6 – Vegetation.

2.2.5.4 Soil Texture and Slope

A large portion of soils (approx. 75%) in the WHCW was derived from siltstones and shales, which produce medium-to-fine textured soils. Soil textures primarily consist of clay loams, silt loams, silty clay loams and clays, and occur in all topographic settings. The more erodible, silty material found within subdrainages generally forms the alluvial parent material from which soils are derived in those locations. Approximately 20 percent of the drainage is comprised of soils derived primarily from sandy alluvium and colluvium or sandstone residium.

Soils within actively changing areas, such as drainages or steep slopes, have little or no soil development, and paralithic contact is generally near the surface. Slopes within the study area are generally steep (10-40%) within the lower reaches, and level to undulating (0-10%) in the upper reaches of the watershed.

Many management decisions for these soils will be based on the soil texture, i.e., percentage of sand, silt, clay, and coarse fragments. Examination of soil textural families, and the distribution of those textural families within the basin will be important to understanding management options for these soils. Soil textural families and the number of major soil series representing each family within the mapped portion of the study area are listed in Table 2.2.5.

Table 2.2.5
WHCW Soil Textural Family Distribution

Textural Family	Acres	%
Sandy	2,048	0.9
Coarse Loamy	44,181	18.9
Fine Loamy	119,631	51.2
Fine Silty	1,356	0.6
Fine	53,784	23.0
Very Fine	354	0.2
Water/Misc.	1,510	0.6
Not mapped	10,736	4.6
Total	**233,600**	**100.0**

As with the DHCW, almost 80 percent of the WHCW is dominated by fine textured soils, including fine loamy, fine silty, fine, and very fine textures. Only 20 percent of the basin is comprised of soils dominated by coarse loamy and sandy soils. While the percentages of each soil type are similar between drainages, it is important to note that the total acreage of coarse loamy and sandy soils is significant in WHCW and may play an important role should land application be used as a water management option. Conversely, the percentage of fine textured soils (clay loam to clays) in WHCW are significantly higher than in DHCW. These fine-textured soils will make management of CBM water applied to them via land application a challenge.

2.2.5.5 Soil Depth

Soils are deep (greater than 40 inches) on alluvial fans, basins and valley alluvium. Shallow soils (less than 20 inches) occur on planes underlain by siltstone, shale and sandstone bedrock, as well as in areas with steeper topography, such as ravines. Moderately deep soils are those between 20 and 40 inches in depth; these soils generally lie on residual upland planes and relatively gentle sideslopes. As noted previously, much of the basin is dominated by soils with limitations on soil depth.

The effective rooting depth, or the ability of the roots to penetrate the soil profile, approximates the total soil depth or is slightly shallower. The depth to bedrock, however, presents some chemical and physical limitations in the suitability of soil map units for reclamation. Since slopes are steep and resulting soil debts are shallow, limited topsoil is available for salvage and use and reclamation of roads, pipelines, drill pads, etc. Soil depth also significantly governs the ability of the soil to store large volumes of water and also alters the ability to leach salts from the root zone as necessary.

2.2.5.6 Soil Permeability

The majority of the soils within the WHCW have moderate-to-low permeability. Areas with sandy soil textures, however, have much higher permeability. Soils with clayey textures have moderately low to low permeability. Soil crusting at the surface also reduces infiltration rates. Areas of inherently high salts and/or sodium generally contain visual panspots or slickspots, which are sealed from any surface infiltration. Such areas will appear as white, smooth areas that are devoid of vegetation. As noted in Section 2.2.5.4, only 20 percent of the soils in the basin can be expected to have moderate to high permeability (sandy and coarse loamy soils). The remaining 80 percent can be expected to have permeabilities ranging from moderately low to very low, with a significant percentage (23%) having very low permeabilities due to high clay content.

Bedrock underlying the soils is generally fractured, which makes it highly permeable in some areas. Limited areas may exist, however, that have impermeable shale layers underlying the soil material. Soils with a high clay content (especially smetitic clays) are subject to cracking upon wetting and drying. Soils adjacent to major drainages tend to be stratified with repeating layers of finer and coarser soil material, which allows for differential lateral flow within these layers.

2.2.5.7 Soil Productivity and Salinity/Sodicity

Soil productivity is naturally low for a portion of the WHCW, due to steep slopes and associated shallow soil depths. As with most areas in this region, soils typically have adequate potassium for plant growth, while nitrogen and phosphorus may be limiting plant growth. Effective precipitation is the chief controlling factor of productivity. Lower precipitation produces less vegetative cover and, consequently, less organic matter for the soil.

Natural areas of salinity/sodium will occur where parent material with higher levels of salinity/ sodium is present, water has promoted percolation of such salts into the profile over time, or natural and man-made dams or diversions have allowed ponding of water at or near the surface. Soil crusting due to inherit or induced sodium in the soil will affect soil productivity by reducing infiltration rates. Salinity will affect osmotic potential in soils and eventual water uptake by plant roots, which would make available precipitation less effective. Of the major soils series found within the mapped portion of the study area, three are classified as Natriagids and two as Calciargids, which would indicate increased levels of sodium and calcium carbonate, respectively. In addition, the 25.9% of the mapped portion of the study area that contains clayey or fine textured soils also likely contains lime and/or sodium at depth in the profile, due to low permeability and deposition of soluble salts. The Absted-Slickspots and Absted-Arvada-Slickspots Complexes are common in the drainage and will generally contain the nitric or sodium affected horizons. Additional series that may contain high salinity/ sodium at depth are Emigha, Moorhead and Leiter.

2.2.5.8 Available Water Capacity

Shallow soils have a lower total water-holding capacity than deeper soils due to lack of depth and ultimate volume. In areas where shale (especially impervious shale) is the underlying bedrock, water will percolate through the soil profile and move laterally when it hits that impervious layer. From a physical standpoint, medium-textured soils have a higher available water capacity than either heavy clay soils or coarse-textured soils.

Total water holding capacity of the basin soils is high due to the high clay content of the soils. However, the average available water holding capacity, that is, water available for plant uptake, for the soils in the project area is low to moderate because soil clays tend to hold water tightly and plants cannot effectively extract much of the water.

2.2.5.9 Seasonal High Water Table

In general, the shallow water table within the study area is likely greater than six feet below the soil surface, especially in upland areas. Narrow drainages, flood plains, alluvial terraces, seep areas, stream beds, and bottom lands are likely areas that will contain varying seasonal water tables, depending upon the overall moisture level in a specific year. Likely salt and/or sodium deposition within these soils will also vary based upon these fluctuating levels. Flooding is rare, typically brief, and generally associated with spring runoff and summer storm events.

2.2.6 Vegetation

As with the DHCW, Ecological (Range) sites are summarized in Table 2.1.6's individual categories and acreage compositions. NRCS range site information for Campbell, Sheridan, and Johnson County is provided in Appendix 1. Ecological vegetation sites are shown by individual soil map unit in the legends on Figures 2.2.2 and 2.2.3. Interpretations on specific vegetation communities can be made from those maps.

Similar to the DHCW, native vegetation in the Three Horses drainages is dominated by grasses with a smaller component of shrubs. Forty-two percent (42%) of the WHCW is on the Loamy, Shallow Loamy 10-14 NP or 15-17 NP ecological sites. Sixty-two of the soil associations are in these categories. The plant communities in these sites are the same as discussed in the DHCW section. The Very Shallow 10-14 NP ecological site, however, is different in that this site in the WHCW contains a component of Rocky Mt. Juniper *(Juniperus scopulorum)* and Utah Juniper *(Juniperus osteosperma).*

Sandy-Shallow Sandy-Sands 10-14 and 15-17 np and combination Sandy with Loamy ecological sites, 43 soil associations, comprise 11% of the watershed. Plant communities are the same as discussed in the DHCW section. An exception is Unit #114, a sandy, shallow sandy, badlands complex that includes a component of Ponderosa pine *(Pinus ponderosa)* in addition to the plant component previously discussed.

Clayey-Shallow clayey 10-14 and 15-17 np plus combination Clayey with Loamy sites, 33 soil associations, comprise 32% of the watershed. Plant communities are the same as discussed in the Dead Horse section with the addition of the following ecological sites. Clayey Overflow 10-14 NP contains Basin wildrye *(Elymus cinereus)* , Canada wildrye *(Elymus canadensis)*, green needlegrass, western wheatgrass, Sandberg bluegrass and Skyline bluegrass. Clayey Overflow 15-17 NP contains green needlegrass western wheatgrass, slender wheatgrass and silver sagebrush. Overflow 15-17 NP contains western wheatgrass, big bluestem, green needlegrass, slender wheatgrass, Canada wildrye and Silver sagebrush. The Dense Clay 10-14 np site contains western wheatgrass, green needlegrass, Sandberg bluegrass, Big sagebrush, Birdfoot sagebrush *(Artemesia spp.)* and Ponderosa pine.

Saline Upland 10-14/saline lowland 10-14 np and combined similar sites are represented by 4 soil associations and comprise only 1% of the watershed. The upland portion contains Gardners saltbush, inland saltgrass, indian ricegrass, Spai, western wheatgrass, bottlebrush squirreltail, greasewood. The lowland position contains Alkali sacatoni, greasewood, Nuttals alkaligrass, sandberg bluegrass, inland saltgrass, and bottlebrush squirreltail.

Lowland 10-14 NP, Lowland 15-17 np, and Loamy combination range site contain seven soil associations and represent 2% of the watershed. The Lowland 10-14 np site is primarily the Haverdad-

Boruff soil association. Haverdad soils contains green needlegrass, cottonwood, needleandthread, slender wheatgrass, western wheatgrass, sandberg bluegrass, and snowberry. Boruff soils contain Nebraska sedge *(Carex nebraskensis)*, western wheatgrass, basin wildrye, and bearded wheatgrass (*Elymus trachycaulus*, subspecies subsecundum). The Lowland 15 – 17 np contains green needlegrass, cottonwood, needleandthread, western wheatgrass, sandberg bluegrass, and silver sagebrush.

The gullied soils (Ustic torriorthent) only account for 2% of the drainage and have an unspecified ecological site. Other miscellaneous sites, including areas not mapped by NRCS, comprise five percent of the drainage.

2.2.7 Surface Water

2.2.7.1 Surface Water Hydrology

Wild Horse Creek is a substantial eastern tributary of the Powder River, encompassing approximately 6% of the Powder River watershed area at Arvada. The total drainage area of Wild Horse Creek is approximately 365 sq. mi. or more than 233,600 acres, and is by far the largest watershed within the Three Horses study area. The confluence of Wild Horse Creek and the Powder River is located adjacent to the Town of Arvada, Wyoming, approximately 24 miles south of the Montana-Wyoming border and approximately two miles downstream of the Wyoming State Highway 14-16 crossing of the Powder River. The WHCW extends from the confluence with the Powder River, approximately 40 miles in a south southeasterly direction, passing beneath I-90 approximately nine miles west of Gillette.

The majority of the WHCW lies within the western edge of Campbell County, but discharges to the Powder River near the easterly edge of Sheridan County and encompasses a very small area of the northeast corner of Johnson County.

2.2.7.2 Surface Water Quantity

Wild Horse Creek is presumed to be an ephemeral stream as classified by WDEQ, i.e.; a stream that under natural conditions flows only in direct response to precipitation in the immediate watershed or in response to snowmelt, and which has a channel bottom that is always above the prevailing water table. Uncertainty exists regarding this classification, as there is limited supporting data upon which to make a conclusion, and the data collected thus far occurred during a drought year.

Natural flow within the WHCW is produced by snowmelt and precipitation runoff events. USGS Gaging/Sampling Station #06317020 is located approximately six miles upstream of the confluence of Wild Horse Creek and the Powder River, upstream of the confluence of the Middle Fork of Wild Horse Creek with Wild Horse Creek. A very limited amount of data has been collected from this station. The USGS began recent monitoring at this station in June 2000, and data is available for an entire "water year" from October 2000 through September 2001. Flow measurements were attempted to be taken in water year 2000; however, no flow was actually measured. Prior to this point, a single discharge measurement was collected by the USGS at this station in 1978. Two discharge measurements have been recorded thus far in 2002.

A summary of the flows recorded for the 2001 water year is presented in Table 2.2.6 below. As can be seen in reviewing the above table, flow events on Wild Horse Creek occurred primarily between the months of January through May. The larger mean daily flows (March - 1.8 cfs), occurred primarily during the spring and were probably produced by snowmelt and spring rain runoffs.

Table 2.2.6
Wild Horse Creek Flow Summary at USGS Gaging Station #06317020 for the 2001 Water Year

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
	Mean Daily cfs											
Total	0	0	0	0.77	0.02	17.62	3.47	0.81	0.04	0	0	0
Mean	0	0	0	0.025	0.001	0.57	0.12	0.026	0.001	0	0	0
Max	0	0	0	0.23	0.01	1.8	0.44	0.08	0.02	0	0	0
Min	0	0	0	0	0	0	0.05	0	0	0	0	0
	Monthly Ac-ft produced											
Ac-ft	0	0	0	1.5	0.04	35	6.9	1.6	0.08	0	0	0

For comparison purposes, a table similar to Table 2.1.7 (which portrays the average number of no-flow days in Dead Horse Creek over the measured period of record) has been prepared and is shown as Table 2.2.7. The former table showed Dead Horse Creek averaging 195.4 days per year of no recorded flow. As Table 2.2.7 shows the number of no-flow days in water year 2001 for Wild Horse Creek is 261 days. Climatological data suggests that 2001 was a drought year within the WHCW.

Table 2.2.7
Average Number of No-flow Days in Wild Horse Creek at USGS #06317020 Gaging Station

Month	Average # of no flow days/month over one-year period of record: 2000 - 2001
September	30
October	31
November	30
December	31
January	14
February	26
March	1
April	0
May	9
June	27
July	31
August	31
Total (days/year)	**261**

Due to the lack of flow monitoring data available during this time period for Wild Horse Creek, it is not possible to characterize the flow regime based upon field measurements. To estimate the surface water flow regime and understand the hydrologic response to a rainfall event, a basic runoff/discharge model was constructed using published storm/precipitation data and using a watershed runoff model.

As with DHCW, a series of six-hour duration precipitation events for various recurrence intervals for the WHCW were compiled from the *Precipitation Frequency Atlas of the Western United States*. (NOAA 1973) A six-hour event approximates a short duration storm/thunderstorm in the PRB. Precipitation isopleths presented in the NOAA atlas show that rainfall depths increase west to east across the WHCW. Precipitation amounts are as follows:

Event	Precipitation Amount (west to east)
2-yr, 6-hr event	1.0 inches to 1.2 inches
5-yr, 6-hr event	1.4 inches to 1.6 inches
10-yr, 6-hr event	1.6 inches to 2.0 inches
25-yr, 6-hr event	2.0 inches to 2.4 inches
50-yr, 6-hr event	2.3 inches to 2.8 inches
100-yr, 6-hr event	2.4 inches to 3.2 inches

Again using the computer program SEDCAD4 to model runoff, and assuming a RCN of 79 for the WHCW, the model was used to simulate a 2-yr, 6-hr event precipitation of 1.1 inches across the entire WHCW. The results of the model suggest a mean daily flow of approximately 395 cfs (1.08 cfs/square/mile) for this magnitude precipitation event. The peak discharge was estimated to be approximately 658 cfs, or 1.8 cfs/sq. mile. These values are likely to be high estimates and are reflective of what would be considered an infrequent, relatively severe storm, as it is unlikely that a thunderstorm would produce a uniform rainfall depth over the entire WHCW. Instead, the typical high-intensity summer thunderstorms can be expected to contribute rainfall to a smaller area, affecting only portions of the WHCW and resulting in a smaller peak discharge and a lower mean daily flow for the duration of the runoff event.

Flow routing and capture may be expected within the WHCW during a storm runoff event. Storm water runoff may be routed through flood irrigation spreader dikes, collected in the numerous stock water ponds and impoundments in the basin and recharge/infiltrate into the alluvium. All of these structures can affect the actual watershed yield, the peak flow and the mean discharge during the runoff event. The number and locations of such structures have not been documented.

Published data or documented field study characterizing the hydrologic conditions of Wild Horse Creek does not currently exist. It is unknown whether there is an alluvial aquifer system. There are no known up-to-date maps of the hydrologic features of the watershed such as springs, irrigation structures, or impoundments. Lacking such data, the development of watershed management plans can be made more difficult, as there is little information upon which to base the interaction of CBM-produced water with natural flows and upon which to judge the net effect of the implementation of a given management technique. An understanding of the watershed response to precipitation, annual watershed yield, and overall flow regime would be important in providing a basis for watershed management planning, such as opportunities for periodic discharge from CBM holding impoundments or the potential for continuous CBM direct discharge to channels within the WCHW.

2.2.7.3 Surface Water Quality

Very little baseline surface water quality data exists for Wild Horse Creek. The USGS has collected five samples of snowmelt and precipitation runoff flows near the confluence of Wild Horse Creek with the Powder River. To supplement this information, EDE collected two grab samples during the summer of 2001 near this same location. Neither grab sample coincided with a precipitation event. The first sample (WH-1) was collected in the upper portion of the WHCW near the confluence with Hay Creek. The second sample (WH-2) was collected near the confluence of Wild Horse Creek with the Powder River.

Table 2.2.8 summarizes available surface water quality.

Table 2.2.8
Wild Horse Creek Surface Water Quality Samples

Sample ID	USGS, 10/20/78	USGS, 3/13/01	USGS, 5/9/01	USGS, 4/10/02	USGS, 5/8/02	WH-1 (EDE) 7/16/01	WH-2 (EDE) 7/16/01
Temp (Deg. C.)	10	3	14.9	3	6.5	n/a	n/a
Discharge (cfs)	0.08	.53	.03	0.11	0.01	n/a	n/a
pH (s.u.)	n/a	7.7	7.9	8.00	7.80	7.90	7.80
EC (μmhos/cm)	6900	1520	4580	1140	3600	4900	2000
CaCO3 (mg/l)	370	333	796	n/a	n/a	624	650
HCO3 (mg/l)	450	406	971	350	581	761	792
CO3 (mg/l)	0	0	0	0	0	0	0
Ca (mg/l)	350	45.3	165	29.5	146	336	18.5
Mg (mg/l)	260	43.5	189	21.7	125	351	8
Na (mg/l)	580	241	808	199	561	537	231
SAR	5.7	6.14	10.19	6.78	8.23	4.89	11.3
K (mg/l)	37	6.23	15.5	4.46	10.2	18.7	5.1
Cl (mg/l)	18	7.8	22.1	5.3	19.5	n/a	n/a
SO4 (mg/l)	2800	483	2100	268	1570	2810	2.3
F (mg/l)	1.3	.4	.6	0.4	0.4	n/a	n/a
SiO2 (mg/l)	8.6	4.7	.8	3.1	3.8	n/a	n/a
TDS (mg/l)	4280	1090	3940	756	2920	3675	1500

The limited water quality sampling data shows that the concentrations of various constituents vary widely between samples. EC values range from 1,140 μmhos/cm to 6,900 μmhos/cm and average 3,520 μmhos/cm. TDS values range from 756 mg/l to 4,280 mg/l, and average 2,594 mg/l. The dominant anionic species, sulfate (SO4), ranged from a low of 2.3 mg/l to 2,810 mg/l, with an average of 1,433 mg/l, while the dominant cation, calcium (Ca), ranged from 18.5 to 350 mg/l and averaged 156 mg/l. SAR values ranged from 4.89 to 11.3 and average 7.56. Sodium concentrations range from 199 mg/l to 808 mg/l and average 451 mg/l.

With respect to water quality, the very small amount of data available on Wild Horse Creek makes difficult an accurate water quality characterization of this watershed. The sample results that are available do not reflect water quality over a sufficient time period to statistically define the water quality variation or to determine if seasonal or other identifiable causes for variation exist. The small total number of samples and the high variability within these few samples results in a substantial level of uncertainty regarding the water quality. Water management, particularly CBM water management, in the WHCW would benefit greatly from additional knowledge about the ambient conditions within Wild Horse Creek.

Figure 2.2.4 graphically portrays available surface water quality on a trilinear diagram. On this diagram, the surface water data are Samples 1 through 5, with the remainder being groundwater samples from coal aquifers for comparison purposes. With the exception of Sample 5 (WH-2), the Wild Horse Creek surface water is of a calcium/sodium sulfate composition. Sample 5 is strongly sodium bicarbonate, suggesting it to be CBM-produced water or other non-alluvial groundwater discharge.

Several observations can be made from the limited surface water quality data available for Wild Horse Creek. First, there are substantial differences between water quality at the upper reach of the watershed and the lower reach, specifically the difference in quality between samples WH-1 (upstream) and WH-2 (downstream). The upstream sample water quality appears to be quite typical of waters expected due to natural runoff from watersheds in the area; i.e., relatively high TDS, and being dominated by calcium sulfate. The downstream sample is much lower in TDS (50% lower) but also shows a dramatic shift in water quality to a strongly sodium sulfate water. When viewed on the trilinear plot of Figure 2.2.4, the downstream sample plots closely with groundwater data from the Wasatch, Anderson and Fort Union Coal seams within the WHCW. The implication is that, within the watershed, there is apparently discharge of coal water either through CBM discharge or through stock wells that alters the basic composition of the stream water in Wild Horse Creek via the change from calcium-based to sodium-based.

It should also be noted that the concentrations for parameters with the surface water quality sample suites taken to date fall within the limits for the designated purposes of irrigation and livestock/wildlife watering (Class III) as defined in Chapter 8 of the WDEQ Water Quality Rules and Regulations (WDEQ 1980) but do not meet the criteria for Class II (Agriculture) for TDS, sulfate and for two or five samples for SAR.

The limited amount of data available on Wild Horse Creek precludes accurate surface water quality characterization within the WHCW. The sample results that are available do not portray surface water quality over a sufficient time period to statistically define the water quality variation, nor to determine if seasonal or other identifiable causes for variations exist. The small total number of samples and the high variability within these few samples result in a substantial level of uncertainty regarding the background WCHW surface water quality. Water management, and particularly CBM water management in the WHCW, would benefit greatly from additional information concerning the ambient surface water quality within the WHCW.

2.2.7.4 Channel Structure and Morphology

Wild Horse Creek is a 4th order channel using the method outlined by Horton (1945), in which first order channels are unbranched tributaries, second order receive first order, etc. The average basin length is approximately 43 miles, and the average width is approximately 11.5 miles, for a basin length-to-width ratio of 3.7. The drainage area of the WHCW is approximately 365.4 square miles (233,856 acres). The maximum elevation in the WHCW is 5,036 feet above mean sea level, and the minimum elevation at the confluence of Wild Horse Creek and the Powder River is 3,640 feet, for a drainage basin relief of 1,362 feet.

The channel morphology of Wild Horse Creek varies considerably from the mouth to the upper reaches of the watershed. Within the lower portions of the Wild Horse Creek flood plain, the channel meanders significantly, and is vertically or nearly-vertically incised to depths of 10-20 feet and widths of 15-20 feet. At many locations, this incised character is expressed as cutbanks or cliffs at the outside corners of meanders, with a broader flood terrace at the inside corners. The incised channel continues up Wild Horse Creek and tributaries, becoming shallower and broader near the headwaters of the drainages. As with most stream channels in the arid to semi-arid regions of Wyoming, Wild Horse Creek is an actively eroding channel in the advanced stages of base level lowering.

The average sinuosity of Wild Horse Creek is approximately 1.62. This suggests that the channel length is 1.62 miles for each mile that the stream flows down the valley. The major tributaries (third order streams) all exhibit less meandering, and the first and second order streams exhibit very little meandering, with sinuosities for these channels approaching 1.0. The average valley slope of Wild Horse Creek is 0.18%, while the channel slope is 0.11%.

The morphological characterization and understanding of the stream channels is important in the development of water management alternatives with respect to channel erodibility, on-stream impoundment construction, alteration of the flow regime, and channel effects on water quality. The existence or absence of an alluvial groundwater system is a function of the geomorphology of the channel and over-bank areas. These characteristics are essentially un-studied and uncharacterized to any useable level of detail in the WHCW.

2.2.7.5 Surface Water Permits

Figure 2.2.5 portrays: (1) locations for points of diversion for adjudicated surface water rights, (2) locations for reservoir permits and (3) a mapping of irrigated lands in the WHCW. Information was again obtained from the recently completed Powder/Tongue River Basin Planning Study. (HKM 2002) Almost all of the reservoir permits are for reservoirs for stock water and domestic use.

2.2.8 Groundwater

2.2.8.1 Groundwater Permits

Figure 2.2.5 also depicts locations for stock water, agricultural and domestic wells permitted by the WSEO within the WHCW as of January, 2001. (HKM 2001) As with the DHCW, this figure does not show WSEO-permitted CBM well locations for either those permitted prior to or subsequent to the January, 2001 date.

2.2.8.2 Groundwater Hydrology

Figure 2.1.12 portrayed the generalized hydro-stratigraphic column of the PRB, of which the WCHW is no exception. Aquifers of importance underlying the WHCW include the Wasatch Formation sandstones and coals of the Tongue River Member of the Fort Union. Little is known about the alluvial aquifer in the area, though it can be assumed that the material is partially saturated and that any aquifers exist as a water table phenomenon.

Wasatch groundwater is primarily found in the numerous lenticular sandstones found in the unit. Laterally discontinuous and generally surrounded by fine grained aspects of the formation, Wasatch sandstones are normally confined above and below. (Bartos and Ogle 2002) Coals and clinker beds can also be saturated and yield useable quantities of water in the Wasatch, although these types of aquifers are thought to be much more local in extent than sandstone zones in the formation.

Groundwater in the Fort Union is contained in coals of the Wyodak-Anderson coal bed system, as well as in sandstones that can lie both above and below the coals. (Bartos and Ogle 2002) Groundwater in the coals is normally confined by overlying shales and below by similar units while the entire Tongue River Member is confined below by the thick shale sequences of the Lebo Member. Similarly, groundwater in the sandstones of the Tullock Member are confined from above by the Lebo Shale.

Cretaceous groundwater is of primary interest for the purposes of injection of CBM waters. Under a Class 5C5 permit issued by the WDEQ, injection into the Wasatch, Fort Union, Lance and Fox Hills can take place—avoiding the more rigid Class II UIC permit application. With the Pierre Shale acting as a barrier to downward groundwater movement and upward contamination from Mesozoic units, Class 5C5 permits allow for recovery of injected water without alteration to water quality.

The groundwater hydrology can be characterized generally as being very similar to the DHCW.

2.2.8.3 Groundwater Quantity

Little is know about alluvial groundwater quantity in the WHCW, although wells completed in the Wasatch make up a good portion of domestic and stock wells in the drainage, suggesting that the alluvium is not a consistent water producer. WSEO data indicates that approximately 200 non-CBM wells have been drilled into the Wasatch, with as many as 25 Wasatch (Felix Coal) CBM wells in the drainage. Characteristics of the domestic and stocks wells indicate an average yield of 12 gpm, with an average static depth of 76 feet BLS. Note that at least seven of these wells had artesian flow upon completion. Little data is available on the Felix Coal CBM wells; at the time of this report, it is unknown as if any production exists from these wells within the WHCW.

Groundwater quantity data from CBM and non-CBM wells in WHCW indicates highly variable aquifer properties within the drainage. Data from over 250 domestic and stock wells registered with the WSEO show average yields to be 20 gpm with average water levels around 235 feet BLS. Of these wells, 29 were recorded as having artesian or flowing characteristics. (Note: no data was available on specific completions for these wells, thus total depth was utilized to determine geologic formation only.)

CBM well depths in the WHCW vary greatly, depending upon the different coals that are targeted for CBM development. Anderson Coal (a common completion in the WHCW) average depths to water vary from 164 feet BLS to over 250 feet BLS, while yields fluctuate from 3 to 11 gpm. Canyon Coal is similar to the Anderson in terms of both depths and water yields, although less data appears to exist for this coal seam. Deeper units such as the Werner and the stratigraphically-similar Cook exhibit average depths around 320 feet BLS. Little depth-to-water information was available for the Wall/Pawnee coals in the area. For the Wyodak-Anderson system as a whole, WO&GCC data indicates average maximum pumping flows at CBM startup of 18 gpm, with most recently reported pumping values averaging 3.7 gpm.

2.2.8.4 Groundwater Quality

While little is known about the alluvial water quality along Wild Horse Creek, Wasatch Formation water quality varies, depending upon distance from recharge zone (both vertically and horizontally), depth and nature of confinement. Where the potential for communication with surface water exists, the water type is likely to be sodium sulfate, whereas deeper groundwater (i.e., farther from the recharge area, or confined) is similar to the DHCW in that it also is a sodium bicarbonate water type. (U.S. Department of Interior BLM, 2001) Figure 2.2.4 portrays groundwater quality on a trilinear diagram in addition so surface water quality values. Note that Wasatch water quality from USGS wells indicates water types with both dominant anionic components (i.e., sulfate and bicarbonate). The difference lies in changes due to biological sulfate reduction occurring at depths, with ion exchange reactions occurring along water pathways and due to the varied characteristics of the host aquifer material.

Table 2.2.9 portrays groundwater quality for major cations and anions on representative samples taken within the WHCW. Wasatch aquifer water quality indicates average TDS values at 1,464 mg/l, with a range from 415-4,080 mg/l. EC values average 1,886 μmhos/cm and range from 679 to 4,190 μmhos/cm. SAR values for the Wasatch also indicate high variability, ranging from a low of 8.2 to a high of 22.5, with an average of 13.6. The dominant cation, sodium (Na), ranges from 158 to 660 mg/l, with a mean of 352 mg/l. Sulfate (SO_4), the dominant anion in three of eight samples, ranges from 1 mg/l to 2,630 mg/l. The higher sulfate concentrations more closely resemble surface water concentrations than other groundwater types in the area.

Fort Union water quality as indicated on the trilinear diagram in Figure 2.2.4 is sodium bicarbonate with little water type variation; however, differences in concentrations can be observed both within and between coal beds. TDS in Fort Union aquifers ranges from 540 mg/l to 1,540 mg/l, averaging 1,133 mg/l. EC in the drainage averages 1,777 μmhos/cm and varies from 860 to 2,420 μmhos/cm. Data indicates that SAR's in the drainage can range from 9 to 29, averaging around 20. Sodium, again the dominant cation, averages 441 mg/l, with concentrations from 220 to 620 mg/l.

Table 2.2.9
Wild Horse Creek Groundwater Quality

	Sample No.	Cond (uS/cm)	pH (s.u.)	Temp C	TDS (mg/l)	Cl (mg/l)	SO4 (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	Fe (mg/l)	Ba (mg/l)	SAR	Br (mg/l)	HCO3 (mg/l)	CO3 (mg/l)	NH4 (mg/l)	F (mg/l)	K (mg/l)	Si (mg/l)	Sr (mg/l)
Fort Union Aquifer	18	860	7.5	24.8	540	12	0.78	14	4.9	220	0.02	0.24	13	0.1	580	*	1.1	0.77	3.9	5.8	0.25
	39	1850	7.7	18.4	1240	11	0.12	19	8.6	500	0.2	0.35	24	0.06	1380	*	2	0.51	6.6	4.7	0.38
	C16	1700	7.3	17	1030	8.3	1	54	29	340	*	*	9	*	1166	*	*	0.9	13	10	*
	54N76W05	1990	8		1290	16	0.3	19	3.5	524	*	*	29.00	*	1430	*	*	*	6	*	*
	53N77W10	2420	8		1540	24	1.3	22	7.8	620	*	*	28.92	*	1710	*	*	*	7.4	*	*
	53N76W26	1840	8.8	21	1160	13	0.4	22	10	440	*	*	19.53	*	1190	55	*	*	14	*	*
Wasatch Aquifer	W6	1850	7.6	18.5	1010	0.3	10	7.7	24	330	*	*	13	*	1244	*	*	1.5	13	10	*
	53N75W4	3850	7.8		3180	7	2070	153	145	660	*	*	9.18	*	240	*	*	*	12	*	*
	53N75W7	4190	8.3	11	4080	4.6	2630	440	159	640	*	*	6.65	*	360	*	*	*	15	*	*
	53N76W22	1260	8	25.3	891	18	15	6.5	3.2	350	*	*	28.09	*	970	*	*	*	7.2	*	*
	52N75W17	831	8.4	16	506	9.3	1	10	3.9	198	*	*	13.45	*	530	9	*	*	3.1	*	*
	52N75W27	679	8.2	11	415	14	1.2	6	0.5	167	*	*	17.61	*	440	*	*	*	1.8	*	*
	50N74W25	689	8.3		415	12	1	13	1.3	158	*	*	11.18	*	420	13	*	*	2.3	*	*
	50N74W31	1740	7.4	11	1220	2.4	768	50	17	312	*	*	9.73	*	120	*	*	*	3	*	*

A summary of the groundwater quality from CBM wells within the WHCW (i.e., from the Fort Union Formation) is shown in Table 2.2.10.

Table 2.2.10
Wild Horse Creek CBM Water Quality[1] (Fort Union Formation) vs. WDEQ Discharge Standards

Parameter	CBM Water Maximum Concentration	CBM Water Mean Concentration (N = 14)	Mean Plus 1 Std. Deviation (Upper 80% Confidence Level)	Mean Plus 2 Std Deviations (Upper 95% Confidence Level)	WDEQ NPDES Discharge Standard
Conductivity	2420 µmhos/cm	1777 µmhos/cm	2290 µmhos/cm	2802 µmhos/cm	7500 µmhos/cm (stock and wildlife water)
Conductivity	2420 µmhos/cm	1777 µmhos/cm	2290 µmhos/cm	2802 µmhos/cm	2000 µmhos/cm (irrigation)
pH	8.8	7.9	8.4	8.9	6.5 – 8.5
TDS	1540 mg/l	1133 mg/l	1469 mg/l	1806 mg/l	5000 mg/l
Oil & Grease	[2]	[2]	[2]	[2]	10 mg/l
Radium 226	[2]	[2]	[2]	[2]	1 pCi/L
Cl	24 mg/l	14.1 mg/l	19.5 mg/l	25 mg/l	46 mg/l
SO_4	1.3 mg/l	0.7 mg/l	1.1 mg/l	1.6 mg/l	3,000 mg/l
Ca	54 mg/l	25 mg/l	39.5 mg/l	54 mg/l	N/A
Mg	29 mg/l	10.6 mg/l	19.9 mg/l	29.3 mg/l	N/A
Na	620 mg/l	440.7 mg/l	583 mg/l	726 mg/l	N/A
Fe dissolved	[2]	[2]	[2]	[2]	0.2997 mg/l
Mn dissolved	[2]	[2]	[2]	[2]	0.629 mg/l
As total	[2]	[2]	[2]	[2]	0.007 mg/l
Ba total	[2]	[2]	[2]	[2]	1.800 mg/l
SAR	29.2	20	28	36	6.0/11[3] irrigation

[1] Values from USGS Open File Report (00-372)
[2] No Data Available
[3] SAR limit of 6 in upper reaches and 11 in lower reaches of Wild Horse Creek

2.2.9 Erosion Potential

As with DHCW, the WHCW study area soil susceptibility to water erosion is generally moderate in the subsurface topsoil horizon, and moderate to severe in the subsoil horizons due to clay content, low permeability and non-cohesive soils, as well as steep slopes. These soils may represent 80 percent of the drainage area. Average runoff potential is moderate to high. Overall wind erosion potential is low to moderate due to the low percentage (20%) of sandy and coarse loamy soils in the basin. (Refer to Section 2.2.5 for further descriptions of the WHCW soils.)

As described in Section 2.2.5, those soils map units in the WHCW occurring on steep upland topography include Unit 225 – Ucross – Iwait – Fairburn loams, 3 to 30% slopes, Unit 312 – Fairburn – Samsil – Badlands Complex, 25 to 60 % slopes, and Unit 217 - Theedle-Shingle Loams, 3 to 30% slopes. These soils have fine loamy, fine silty, and fine textures, and erosion potential is moderate to very high depending upon texture, vegetative cover, and slope steepness.

High saline and/or sodic soils that are susceptible to surface erosion include: Emigha and sodic-Arvada. These soils occur in Map Units 102 – Arvada, thick surface – Arvada slickspots complex, Unit 142 – Emigha-sodic Arvada, Unit 252 – Absted-slickspots Complex, and Unit 253 – Absted-Arvada-slickspots complex. Units 102, 147, and 252 each comprise less than ½% of the drainage. Unit 253 comprises less than 1% of the drainage.

The Wild Horse Creek floodplain and local terrace soils are dominated by Unit 298 – Haverdad-Boruff Complex, 0 to 6% slopes. The Haverdad soils have coarse loamy to fine loamy textures, and erosion potential is moderately low to moderately high, depending on slope, texture and vegetative cover. The Boruff soils are fine loamy, and erosion potential is moderate to moderately high. These soils comprise approximately 1.5 percent of the drainage.

Sideslopes, alluvial fans, terraces, and colluvial deposits in the drainage are occupied by Unit 255 – Ulm-Bidman Complex, 0 to 6% slopes. These soils have fine loamy to fine surface textures, and the erosion potential is moderately high to high, depending of slope steepness and vegetative cover..

Similar to the DHCW, while the above discussion describes the dominant soil units in the drainage, numerous soil map units occur, and an individual assessment of erosion potential should be made by referring to the Map Unit descriptions in Appendix 1.

2.3 SPOTTED HORSE CREEK

2.3.1 Geography and Topography

The SHCW is located within Campbell and Sheridan Counties. It extends upstream from the Powder River in an easterly and southerly direction, with the confluence being approximately ten miles north of U.S. 14-16's crossing of the Powder River. Figure 2.3.1 depicts the watershed boundary and the enclosed 61,666 acres (approximately 96 square miles).

The highest elevation in the watershed is 4,575 feet, located in Section 28, T54N, R74W. The confluence with the Powder River is the lowest point in the watershed, which is at elevation 3,520 feet. The total elevation difference is thus 1,055 feet over a horizontal distance of approximately 23 miles (46 feet/mile, or a valley slope of 0.87%), making the SHCW steeper than the WHCW but not as steep as the DHCW.

2.3.2 Surface Ownership

Figure 2.1.2 depicts the surface ownership within the SHCW. (U.S. Department of Interior, BLM 2002) The amount of land and percentage of surface ownership among federal, state and private interests in the SHCW is as shown in Table 2.3.1.

Table 2.3.1
Spotted Horse Creek Watershed Surface Ownership

Ownership	Area (sq. mi.)	%
Federal	9.9	10.3
State	7.4	7.7
Private	79.0	82.0
Totals	96.3	100.0

There is a greater percentage of private interests holding surface rights within the SHCW when compared to the other two basins within the Three Horses watersheds.

2.3.3 Minerals Ownership

Figure 2.1.3 portrays the ownership of minerals within the SCHW. (U.S. Department of Interior, BLM 2002) The amount of land and percentage of minerals ownership between federal and other interests within this watershed is as follows:

Table 2.3.2
Spotted Horse Creek Watershed Minerals Ownership

Ownership	Area (sq. mi.)	%
Federal	51.0	53.0
Other	45.3	47.0
Totals	96.3	100.0

2.3.4 Geology

Surface geology of the Spotted Horse Creek area is composed of Recent or Quaternary alluvium, minor thicknesses of the Eocene Age Wasatch Formation and primarily of the Tongue River Member of the Fort Union Formation. Alluvium in the drainage is most prominent on the main stem of Spotted Horse Creek and decreases in thickness to the southeast among the tributaries. Thickness of the alluvium is quite variable, and little data exists about this component. Un-eroded remnants of the Wasatch exist in the drainage; however, areas off of the Spotted Horse Creek channel appear to be dominated by the upper sections of the Fort Union. (WO&GCC 2002)

The Tongue River Member of the Fort Union is the primary coal-bearing portion of the formation. A number of coals are producing CBM in the drainage. From stratigraphic top to bottom, these coals include: Smith, Swartz, Anderson, Canyon (upper), Canyon (lower), Wall and Lower Wall. The majority of production appears to be derived from the Canyon, Cook, and Wall Coals, with minor amounts of gas from the Smith and Anderson units. (WO&GCC 2002) CBM well completions indicate a coal thickness of 33 –55 feet for the majority of wells in the drainage. The general dip of the formations within the SHCW is also to the west at approximately 1°.

Similar to the other two drainages, the Tongue River Member is underlain by the Lebo Shale and Tullock Members of the Fort Union. Thickness for these members in SHCW approaches 2,000 feet, although limited drilling data actually exists.

Table 2.3.3 provides a summary of the coal seam thicknesses within the SHCW. (WO&GCC 2002)

Table 2.3.3
SHCW Coal Seam Thickness Summary

Coal Seam	Number of Data Points	Mean Thickness (ft)	Maximum Thickness (ft)	Minimum Thickness (ft)
Anderson	17	30.3	59	22
Canyon	137	41	76	12
Little Canyon	12	55	100	32
Cook	119	33.6	79	8
Wall/Pawnee	45	41.8	84	13

Late Cretaceous formations underlying the SHCW include the Lance, Fox Hills and Pierre Shale. These potential injection zones lie well below the CBM production intervals and represent the deepest available formations that could allow for issuance of a Class 5C5 injection permit. Depths to the Lance, Fox Hills and Pierre Shale in the drainage are derived from the single injection well permitted for the area and are 2,879 feet, 3,953 feet and 3,985 feet BLS, respectively. (WO&GCC 2002)

2.3.5 Soils

2.3.5.1 General

As with the DHCW and WHCW, topography within the SHCW ranges from relatively small areas of nearly level to gently sloping uplands in the upper reaches of the SHCW, to much larger areas of steep, dissected slopes in the mid-to-lower portions. Stream terraces and floodplains in this drainage are far more prominent than in the DHCW.

Campbell County baseline soils information was obtained from preliminary Order 3 NRCS soils mapping from North Campbell County, including non-published mapping unit descriptions, legends, etc. from the NRCS office in Gillette, Wyoming. None of the mapping or databases for North Campbell County is available in digital format as USDA NRCS Soil Survey Geographic (SSURGO) data. Therefore, all Campbell County SHCW soils have been digitized into appropriate databases to allow digital production of soil maps. Because Campbell County information is preliminary, some soil map units did not have correlated map unit descriptions. These soils are identified with four-digit soil unit numbers and are treated as miscellaneous soils in this report.

Sheridan County baseline soils information and maps were obtained from the published 1998 Sheridan County Soil Survey. As with Campbell County, this soils information was not available in digital format, thus all Sheridan County soils in the SHCW were digitized into GIS format. Where possible, Sheridan County soil map units were cross-referenced with Campbell county map units, and similar units were assigned the same map unit number to lessen confusion between counties. Unique Sheridan County units were assigned unique map unit numbers.

Soils mapping for the SHCW are presented in this report as Figure 2.3.2.

2.3.5.2 General Soil Characteristics

The SHCW is a major tributary of the Powder River, which occupies a structural basin bounded on the west by the Big Horn Mountains and on the east by the Black Hills. The Wasatch Formation of the Eocene Age is exposed over the entire drainage basin and has a distinct impact as parent material on the subsequent development of soils and their distribution. Textures in the Wasatch are variable, and include sandstone, siltstone, mudstone, and conglomerate.

Within the mapped portion of the drainage, soils are primarily included in the following major soil orders: Alfisols; Aridisols; Entisols; Inceptisols; and Mollisols These soils formed under a dry, cool climate with predominant spring moisture. Soils generally have low organic matter that is limited to the upper horizon; higher values may be found in their drainage bottoms where vegetation productivity and moisture conditions are higher. Soils are formed from residuum on tertiary bedrock-controlled uplands, and in quaternary alluvium and colluvium along stream channels and toeslopes. Principal parent materials of soils in the project area are shales, siltstones, sandstones, and mixed alluvium.

2.3.5.3 Distribution of Mapped Units

The NRCS Order 3 Sheridan County published soil maps and the Campbell County unpublished soil maps are considered a gross scale approximation of the soils within the SHCW. On a smaller scale, inclusions of secondary soil types in the larger map units are likely. Soils within a drainage bottom are especially variable due to the dynamic nature of the processes that deposited the parent material or alluvium. Deposition will vary by size of the flow event and intensity of channel meandering over time. Table 2.3.4 summarizes each map unit by total acres and percentage of area. Soils representing less than one half of one percent of the study area (generally less than 350 acres total area) are listed in the table as "miscellaneous" soils and are not detailed here. Detailed map unit descriptions, including miscellaneous soils, are presented in Appendix 1.

Table 2.3.4
Soil Mapping Units and Areas Within the SHCW

Map Unit	Acres	%		Map Unit	Acres	%
330	5,075	8.2		134	886	1.4
312	4,232	6.9		249	794	1.3
205	3,068	5.0		261	774	1.3
216	2,923	4.7		183	772	1.3
320	2,767	4.5		310	747	1.2
225	2,707	4.4		260	641	1.0
331	2,462	4.0		103	633	1.0
167	1,906	3.1		337	618	1.0
305	1,866	3.0		201	599	1.0
116	1,674	2.7		168	577	0.9
206	1,585	2.6		224	552	0.9
255	1,494	2.4		111	505	0.8
184	1,389	2.3		294	488	0.8
329	1,136	1.8		106	477	0.8
298	1,116	1.8		157	470	0.8
182	1,109	1.8		146	428	0.7
307	1,085	1.8		131	414	0.7
289	1,003	1.6		221	412	0.7
283	988	1.6		248	358	0.6
288	933	1.5		268	350	0.6
107	901	1.5		Misc.	7,865	12.8
228	887	1.4				
				Total	**61,666**	**100.0**

The soil distribution in SHCW is somewhat unique compared to DHCW and WHCW, in that a single unit is not as dominant as units in the other drainages. In other words, the units are dispersed much more evenly over the basin in terms of total acreages and percentages of acres. While the SHCW contains over 100 soil map units, including variances of similar units, 42 map units comprise in excess of 87 percent of the drainage basin. Approximately 13 percent of the mapped area was comprised of the remaining soil units and are considered minor soils for this discussion.

While more units are represented as significant in the drainage basin, the interpretation of many of those units for water management purposes are nearly the same. For example, the unit comprising the highest percentage (8.2%) of the area is Unit 330, Ironbutte-Fairburn-Mittenbutte Complex, Rangeland, 6 to 40% slopes. This unit is present on ridges, summits, and shoulders of the uplands and is very steep and often highly eroded and gullied. Unit 312, Fairburn-Samsil- Badlands Complex, 25 to 60 percent slopes is the second largest unit and comprises 6.9 percent of the drainage. It is also present on summits, shoulders, and heavily dissected gullies. Much of these units are shallow to bedrock, commonly ranging from 10 to 40 inches to bedrock comprised of sandstone and shales. Textures are fine loamy (loams to clay loams). Fifteen percent of Unit 312 is comprised of highly erosive, fine textured badlands, nearly devoid of vegetation.

SHCW is also unique compared to the other two drainages in that several soil units containing wooded areas are present in the uplands of the drainage basin. While several of the SHCW area are wooded, the two units comprising the largest acreage are Unit 320, Shingle-Taluce-Badlands complex, Wooded, 6 to 45% slopes and Unit 331, Ironbutte-Fairburn, Mittenbutte Complex, Wooded, 6 to 40 % slopes. These units comprise approximately 9.5 percent of the drainage, combined. Unit 320 occurs on summits, shoulders, and ridges and textural families range from fine loamy to fine (clay loams to clays).

Approximately 15 percent of the unit is wooded. Unit 331 is physically similar to Unit 330 described above, except approximately 15 percent of the unit is wooded.

The main map unit within the Spotted Horse Creek floodplain and adjacent terraces is Unit 298, Haverdad-Boruff Complex, developed on 0-6% slopes. Textures are variable ranging from sandy to fine loamy depending on depositional environments. Vegetation distribution varies with microtopography. The channel itself may be vegetated with various hydrophytic species or consist of bare areas resulting from late-season pooling. Areas adjacent to the channel will consist of species tolerant of inundation cycles and/or salt deposition. This tolerance will likely decrease as one moves away from the channel. Salt deposition will also likely move deeper into the soil profile as one moves away from the channel. Secondary terraces within these developed channels are common. Pockets of high saline/sodic soils are interspersed throughout the landscape, including adjacent terraces. These soils may be comprised of Absted-slickspots Complex (Unit 252) or the Absted-Arvada-Slickspots Complex (Unit 253).

Alluvial terraces and fans adjacent to the Spotted Horse floodplain may often consist of Unit 167, Jaywest-Moorhead loams, 0 to 6 % slopes and Unit 255, Ulm-Bidman Complex, 0 to 6% slopes. These soils are relatively flat compared to the adjacent uplands and side areas and are often comprised of clay loam to clay textures. These soils may become important for water management options, particularly for land application. However, the fine textures make land application management difficult.

Vegetation descriptions of these units are provided in Section 2.3.4.

2.3.5.4 Soil Texture and Slope

As with the other drainages, a large portion of soils (approximately 64 percent) in the SHCW were derived from siltstones and shales, which produce medium-to-fine textured soils. Soil textures for these soils primarily consist of clay loams, silt loams, silty clay loams and clays, and occur in all topographic settings. The more erodible, silty material found within subdrainages generally forms the alluvial parent material from which soils are derived in those locations.

SHCW does have significantly more sandy and coarse loamy soils in the drainage basin when compared to DHCW and WHCW. Approximately 34 percent of the drainage is comprised of soils derived primarily from sandy alluvium, colluvium or sandstone residium as compared to only 20 percent in both DHCW and WHCW. These soils will be significant when evaluating land application and other water management options.

Soils within actively changing areas, such as drainages or steep slopes, have little or no soil development, and paralithic contact is generally near the surface. Slopes within the study area are generally steep (10-40%) within the lower reaches, and level to undulating (0-10%) in the upper reaches of the watershed.

Many management decisions for these soils will be based on the soil texture, i.e., percentage of sand, silt, clay, and coarse fragments. Examination of soil textural families, and the distribution of those textural families within the basin will be important to understanding management options for these soils. Soil textural families and the number of major soil series representing each family within the mapped portion of the study area are listed in Table 2.3.5.

Table 2.3.5
SHCW Soil Textural Family Distribution

Textural Family	Acres	%
Sandy	146	0.2
Coarse Loamy	20,705	33.6
Fine Loamy	27,084	43.9
Fine Silty	849	1.4
Fine	11,643	18.9
Very Fine	0	0.0
Water/Misc.	1,239	2.0
Not mapped	0	0.0
Total	**61,666**	**100.0**

2.3.5.5 Soil Depth

Soils are deep (greater than 40 inches) on alluvial fans, basins and valley alluvium. Shallow soils (less than 20 inches) occur on planes underlain by siltstone, shale and sandstone bedrock, as well as in areas with steeper topography such as ravines. Moderately deep soils are those between 20 and 40 inches in depth; these soils generally lie on residual upland planes and relatively gentle sideslopes. As noted previously, much of the basin is dominated by soils with limitations on soil depth.

The effective rooting depth, or the ability of the roots to penetrate the soil profile, approximates the total soil depth or is slightly shallower. The depth to bedrock, however, presents some chemical and physical limitations in the suitability of soil map units for reclamation. Since slopes are steep and resulting soil debts are shallow, limited topsoil is available for salvage and use and reclamation of roads, pipelines, drill pads, etc. Soil depth also significantly governs the ability of the soil to store large volumes of water and also alters the ability to leach salts from the root zone as necessary.

2.3.5.6 Soil Permeability

The majority of the soils within the SHCW have moderate-to-low permeability. Areas with sandy soil textures, however, have much higher permeability. Soils with clayey textures have moderately low to low permeability. Soil crusting at the surface also reduces infiltration rates. Areas of inherently high salts and/or sodium generally contain visual panspots or slickspots, which are sealed from any surface infiltration. Such areas will appear as white, smooth areas that are devoid of vegetation. As noted in Section 2.3.5.4, approximately 34 percent of the soils in the basin can be expected to have moderate to high permeability (sandy and coarse loamy soils). The remaining 66 percent can be expected to have permeabilities ranging from moderately low to very low, with a significant percentage (19%) having very low permeabilities due to high clay content.

Bedrock underlying the soils is generally fractured, which makes it highly permeable in some areas. Limited areas may exist, however, that have impermeable shale layers underlying the soil material. Soils with a high clay content (especially smetitic clays) are subject to cracking upon wetting and drying. Soils adjacent to major drainages tend to be stratified with repeating layers of finer and coarser soil material, which allows for differential lateral flow within these layers.

2.3.5.7 Soil Productivity and Salinity/Sodicity

Soil productivity is naturally low for a portion of the SHCW due to steep slopes and associated shallow soil depths. As with most areas in this region, soils typically have adequate potassium for plant growth, while nitrogen and phosphorus may be limiting plant growth. Effective precipitation is the chief controlling factor of productivity. Lower precipitation produces less vegetative cover and, consequently, less organic matter for the soil.

Natural areas of salinity/sodium will occur where parent material with higher levels of salinity/ sodium is present, water has promoted percolation of such salts into the profile over time, or natural and man-made dams or diversions have allowed ponding of water at or near the surface. Soil crusting due to inherit or induced sodium in the soil will affect soil productivity by reducing infiltration rates. Salinity will affect osmotic potential in soils and eventual water uptake by plant roots, which would make available precipitation less effective. Of the major soils series found within the mapped portion of the study area, three are classified as Natriagids and two as Calciargids, which would indicate increased levels of sodium and calcium carbonate, respectively. In addition, the 25.9% of the mapped portion of the study area that contains clayey or fine textured soils also likely contains lime and/or sodium at depth in the profile, due to low permeability and deposition of soluble salts. The Absted-Slickspots and Absted-Arvada-Slickspots Complex are common in the drainage and will generally contain the nitric or sodium affected horizons. Additional series that may contain high salinity/ sodium at depth are Emigha, Moorhead and Leiter.

2.3.5.8 Available Water Capacity

Shallow soils have a lower total water-holding capacity than deeper soils due to lack of depth and ultimate volume. In areas where shale (especially impervious shale) is the underlying bedrock, water will percolate through the soil profile and move laterally when it hits that impervious layer. From a physical standpoint, medium-textured soils have a higher available water capacity than either heavy clay soils or coarse-textured soils.

Total water holding capacity of the basin soils is high due to the high clay content of the soils. However, the average available water holding capacity, that is, water available for plant uptake, for the soils in the project area is low to moderate because soil clays tend to hold water tightly and plants cannot effectively extract much of the water.

2.3.5.9 Seasonal High Water Table

In general, the shallow water table within the study area is likely greater than six feet below the soil surface, especially in upland areas. Narrow drainages, flood plains, alluvial terraces, seep areas, stream beds, and bottom lands are likely areas that will contain varying seasonal water tables, depending upon the overall moisture level in a specific year. Likely salt and/or sodium deposition within these soils will also vary based upon these fluctuating levels. Flooding is rare, typically brief, and generally associated with spring runoff and summer storm events.

2.3.6 Vegetation

As with both the DHCW and WHCW, Ecological (Range) sites are summarized in Table 2.1.6's individual categories and acreage compositions. NRCS range site information for Campbell, Sheridan, and Johnson County is provided in Appendix 1. Ecological sites by individual soil map unit can be located in the legend on Figure 2.3.2. Interpretations on specific vegetation communities can be made from those maps.

Similar to both the DHCW and WHCW, native vegetation in the SHCW is dominated by grasses with a smaller component of shrubs. Forty-two percent (42%) of the Spotted Horse Creek watershed is on the Loamy, Shallow Loamy 10-14 np or 15-17 np ecological sites. Forty Seven of the soil associations are in these categories. The plant communities in these sites are the same as discussed in the DHCW and WHCW sections. The Very Shallow 10-14 np ecological site is different in that this site in the SHCW contains a component of Rocky Mt. Juniper *(Juniperus scopulorum)* and Utah Juniper *(Juniperus osteosperma).*

Two major soil map units, Unit 312 and Unit 331, are similar to the Loamy-shallow Loamy vegetation communities, but have significant stands of ponderosa pine (*Pinus ponderosa*). These units comprise 11.5% of the area and are located in the uplands above Spotted Horse Creek.

Sandy-Shallow sandy-Sands 10-14 and 15-17 NP and combination Sandy with Loamy ecological sites, 19 soil associations, comprise 10% of the watershed. Plant communities are the same as discussed in the DHCW and WHCW sections. An exception is Unit #114, a sandy, shallow sandy, badlands complex, that includes a component of Ponderosa pine *(Pinus ponderosa)* in addition to the plant component previously discussed.

Clayey-Shallow clayey 10-14 and 15-17 NP plus combination Clayey with Loamy sites, 24 soil associations, comprise 32% of the watershed. Plant communities are the same as discussed in the DHCW and WHCW sections with the addition of the following ecological sites. Clayey Overflow 10-14 np contains Basin wildrye (*Elymus cinereus*) , Canada wildrye (*Elymus canadensis*), green needlegrass, western wheatgrass, Sandberg bluegrass and Skyline bluegrass. Clayey Overflow 15-17 np contains green needlegrass western wheatgrass, slender wheatgrass and silver sagebrush. Overflow 15-17 np contains western wheatgrass, big bluestem, green needlegrass, slender wheatgrass, Canada wildrye and Silver sagebrush. The Dense Clay 10-14 np site contains western wheatgrass, green needlegrass, Sandberg bluegrass, Big sagebrush, Birdfoot sagebrush (*Artemesia spp.*) and Ponderosa pine.

Saline Upland 10-14/saline lowland 10-14 np and combined similar sites are represented by 2 soil associations and comprise less than 1 percent of the watershed. The upland portion contains Gardners saltbush, inland saltgrass, indian ricegrass, Alkali sacaton, western wheatgrass, bottlebrush squirreltail, greasewood. The lowland position contains Alkali sacaton, greasewood, Nuttals alkaligrass, sandberg bluegrass, inland saltgrass, and bottlebrush squirreltail.

Lowland 10-14 np, Lowland 15-17 NP, and Loamy combination range site contain 4 soil associations and represent 3% of the watershed. The Lowland 10-14 np site is primarily the Haverdad-Boruff soil association. Haverdad soils contains green needlegrass, cottonwood, needleandthread, slender wheatgrass, western wheatgrass, sandberg bluegrass, snowberry. Boruff soils contain Nebraska sedge (*Carex nebraskensis*, western wheatgrass, basin wildrye, bearded wheatgrass (*Elymus trachycaulus*, subspecies *subsecundum*). The Lowland 15 – 17 np contains green needlegrass, cottonwood, needleandthread, western wheatgrass, sandberg bluegrass, and silver sagebrush.

2.3.7 Surface Water

2.3.7.1 Surface Water Hydrology

Spotted Horse Creek is an eastern tributary of the Powder River. The total drainage area of Spotted Horse Creek is approximately 96 square miles (or 61,666 acres) and is the smallest watershed within the Three Horses study area. The confluence of Spotted Horse Creek and the Powder River is located approximately 11 miles south of the Wyoming-Montana border. The SHCW extends from its confluence with the Powder River in a south southeasterly direction for approximately 23 miles. It is approximately bisected by U.S. Highway 14/16. The majority of the SHCW lies within the western edge of Campbell County, but discharges to the Powder River within the eastern edge of Sheridan County.

2.3.7.2 Surface Water Quantity

Spotted Horse Creek appears to be an ephemeral stream as classified by WDEQ; i.e., it is a stream that under natural conditions flows only in direct response to precipitation in the immediate watershed or in response to snowmelt, and which has a channel bottom that is always above the prevailing water table. Uncertainty exists regarding this classification due to the lack of discharge monitoring data on Spotted Horse Creek.

There are no current or past USGS gaging stations located on Spotted Horse Creek and no State or other public hydrologic monitoring currently ongoing or planned. This data void has potential substantial implications for development of a watershed management plan or determining the best management practices for CBM produced water.

Due to the lack of flow monitoring data for the SHCW, it is not possible to characterize the flow regime based upon field measurements. To estimate the surface water flow regime and understand the hydrologic response to a rainfall event, a basic runoff/discharge model (similar to that used for DHCW and WHCW) was constructed using published storm/precipitation data and using a watershed runoff model and a series of six-hour duration precipitation events for various recurrence intervals.

Calculated precipitation amounts for the SHCW are essentially the same as for the WHCW and are as follows:

Event	Precipitation Amount (west to east)
2-yr, 6-hr event	1.0 inches to 1.2 inches
5-yr, 6-hr event	1.4 inches to 1.6 inches
10-yr, 6-hr event	1.6 inches to 2.0 inches
25-yr, 6-hr event	2.0 inches to 2.4 inches
50-yr, 6-hr event	2.3 inches to 2.8 inches
100-yr, 6-hr event	2.4 inches to 3.2 inches

Again using the computer program SEDCAD 4 and an RCN of 79, results of the model suggest a mean daily flow of approximately 153 cfs for this magnitude precipitation event within the SHCW (1.57 cfs / square mile). The peak discharge was estimated to be approximately 287 cfs (2.95 cfs / square mile.). These values are again likely to be high estimates and are reflective of what would be considered an infrequent, relatively severe storm.

As with DHCW and WHCW, the existence of flood irrigation spreader dikes, collection within the numerous stock water ponds and impoundments in the basin and recharging of the alluvium will affect the watershed yield, the peak flow and the mean discharge during the runoff event.

Published data or documented field study characterizing the hydrologic conditions of Spotted Horse Creek does not currently exist. It is unknown whether there is an alluvial aquifer system. There are no known up-to-date maps of the hydrologic features of the watershed, such as springs, irrigation structures, or impoundments.

2.3.7.3 Surface Water Quality

Very little, if any, true background or baseline surface water quality data exists for Spotted Horse Creek. No public entity (USGS, BLM, WDEQ) has published data for the surface water within the SHCW. EDE installed and operated an automatic sampler triggered by stream flow during portions of the study period, with a sampler placed on the lower reach of Spotted Horse Creek approximately ½ mile above the confluence with the Powder River. A total of twenty-four samples were collected from a thunderstorm event on July 23, 2001. All 24 samples were field tested for pH and EC, and three samples were collected at the beginning, midpoint and end of the sampling run (5-minute intervals over a 120-minute period).

Table 2.3.6 summarizes the water quality data collected from the thunderstorm event on July 23rd, and Figure 2.3.3 portrays pH and EC for the duration of sampling during this event. EC values range from a low of 925 μmhos/cm to a high of 1,777 μmhos/cm. For comparison purposes, water quality values from a recent Petroleum Association of Wyoming (PAW) report, in which it responded to an Environmental Protection Agency study on PRB water management alternatives, are included along with the EDE values. (Petroleum Association of Wyoming) In comparing the PAW baseline data to that collected by EDE, surface water quality samples collected by PAW indicate a poorer surface water quality than those collected by EDE.

Table 2.3.6
Spotted Horse Creek Surface Water Quality

Monitoring Point	SHCW Baseline POC (PAW)	SHCW Carson-5-W	SH-1 (EDE)	SH-12 (EDE)	SH-24 (EDE)
Sample date	4/7/00	8/10/00	7/23/01	7/23/01	7/23/01
Flow (cfs)	n/a	n/a			
pH (s.u.)	7.58	7.95	7.43	7.21	7.69
EC (umhos/cm)	6110	3820	1153	925	1415
TDS calc. (mg/l)*	5890	3550	865	714	1061
HCO3 (mg/l)	755	201	195	86	300
SO4 (mg/l)	3620	2430	402	332	417
Cl (mg/l)	21	10	n/a	n/a	n/a
Ca (mg/l)	278	249	82.4	92.7	58.1
Mg (mg/l)	359	317	31.5	32.8	34.6
K (mg/l)	n/a	n/a	13.4	17.1	12
Na (mg/l)	962	351	136	59.9	201
SAR	8.98	3.5	3.23	1.36	5.16

*Note: PAW TDS values not calculated

Concentrations of various constituents during the July 23rd storm event, with the concentrations most likely affected by timing of tributary flows arriving at the sampling site.

Figure 2.3.4 shows three surface water quality values on a trilinear diagram along with coal water quality from within Spotted Horse Creek. Spotted Horse Creek surface water is of a calcium sulfate composition, in strong contrast to the groundwater samples that show a strongly sodium bicarbonate composition. This is similar to both DHCW and WHCW surface water quality values. SAR values range from 1.36 to 5.16, with an average of 3.25. Sodium concentrations ranged from 59.9 mg/l to 201 mg/l.

Several preliminary conclusions may be drawn from the surface water quality sampling results from Spotted Horse Creek. First of all, water quality over the course of a single event can be highly variable. Secondly, the concentrations of parameters within the limited water quality samples fall within the limits for the designated purposes of irrigation and livestock watering as defined in Chapter 8 of the WDEQ Water Quality Rules and Regulations. Thirdly, the surface and groundwater quality again contrast greatly with respect to major ionic constituents.

With respect to surface water quality, the very small amount of data available on Spotted Horse Creek makes an accurate water quality characterization of this watershed difficult. The sample results that are available do not reflect water quality over a sufficient time period to statistically define the water quality variation or to determine if seasonal or other identifiable causes for variation exist. The small total number of samples and the high variability within these few samples result in a substantial level of uncertainty regarding the water quality. As with the other drainage basins, water management in the SHCW, and particularly CBM water management, would benefit greatly from additional knowledge about the water quality within Spotted Horse Creek.

2.3.7.4 Channel Structure and Morphology

Spotted Horse Creek is a 4^{th} order channel using the method outlined by Horton. (1945) The average basin length is 15.5 miles, and the average width is 4.8 miles, for a basin length-to-width ratio of approximately 3.2.

The average sinuosity of Spotted Horse Creek is approximately 1.54. This suggests that the channel length is 1.54 miles for each mile the stream flows down the axis of the valley. The major tributaries (third order streams) all exhibit less meandering, and the first and second order streams exhibit very little meandering, with sinuosities for these channels approaching 1.0. The average valley slope of Spotted Horse Creek is 0.35% while the channel slope is 0.23%.

The morphological characterization and understanding of the stream channels are important in the development of water management alternatives with respect to channel erodibility, on-stream impoundment construction, alteration of the flow regime, and channel effects on water quality. The existence or absence of an alluvial groundwater system is a function of the geomorphology of the channel and over bank areas. These characteristics are essentially unstudied and uncharacterized in any useable level of detail in the SHCW.

2.3.7.5 Surface Water Permits

Figure 2.3.5 portrays: (1) locations for points of diversion for adjudicated surface water rights, (2) locations for reservoir permits and (3) a mapping of irrigated lands in the SHCW. As with the DHCW and WHCW, information was obtained from the recently completed Powder/Tongue River Basin Planning Study. (HKM 2001)

2.3.8 Groundwater

2.3.8.1 Groundwater Permits

Figure 2.3.5 also depicts locations for stock water, agricultural and domestic wells permitted by the WSEO within the SHCW as of January, 2001. (HKM 2001) It does not show WSEO-permitted CBM well locations for either those permitted prior to or subsequent to the January, 2001 date.

2.3.8.2 Groundwater Hydrology

Figure 2.1.12 portrayed the generalized hydro-stratigraphic column of the PRB, which generally represents the area of the SHCW with one exception: the Wasatch Formation. With little significant Wasatch Formation thickness in the SHCW, the aquifer is of little concern. Similarly, there is very little data on alluvial aquifer properties in the area.

Groundwater in the Fort Union is contained in coals of the Wyodak-Anderson coal bed system, as well as in sandstones that can lie both above and below the coals. Groundwater in the coals is normally confined by overlying and underlying shales, while the entire Tongue River Member is confined below by the thick shale sequences of the Lebo Member. Varying static levels in wells completed in different coals indicate that confining layers exist between producing units. Underlying sandstones of the Tullock Member are confined from above by the Lebo Shale and fine grained portions of the Lance.

Cretaceous groundwater is of primary interest for the purposes of injection of CBM waters. Under a Class 5C5 permit issued by the WDEQ, injection into the Wasatch, Fort Union, Lance and Fox Hills can take place—avoiding the more rigid Class II UIC permit application. With the Pierre Shale acting as a barrier to downward groundwater movement and upward contamination from Mesozoic units, Class 5C5 permits allow for recovery of injected water without alteration to water quality.

2.3.8.3 Groundwater Quantity

WSEO data provides valuable insight into well yields and static water levels in the SHCW. (Wyoming State Engineer's Office 2002) Records indicate that there are approximately 110 domestic and stock wells in the drainage, with an average yield of 12 gpm and average static level at 214 feet BLS. These records also indicate at least 12 flowing wells or springs in the area. Similar to the WHCW, properties from the various coal beds being developed vary greatly across the drainage. The shallowest developed coal in the drainage, the Smith Coal, has seen little to no production, whereas the next stratigraphically lower coal has seen moderate production. The Anderson Coal, averaging 10 to 30 gpm of discharge required for CBM development, has static water levels around 250 feet BLS - the shallowest of the producing coals in the drainage. Canyon Coal characteristics range from 6 to 27 gpm, depending on location, while water levels vary from 300 to 477 feet BLS. (For simplicity, note that this includes Upper and Lower Canyon values as well.) Underlying the Canyon group in the SHCW is the Cook Coal, which indicates average yields from 16 to 27 gpm and static water levels from 505 to 577 BLS. The lowest producing coal in the drainage is the Wall/Pawnee Coal. Average water production for the unit varies from 9 to 29 gpm, while static levels range from 214 to 402 BLS.

WO&GCC data for the drainage portrays average maximum startup yields for all CBM-producing wells in the drainage at 15 gpm, with a maximum of 66 gpm. Data from the same source indicates that during the most recent reporting period, the wells were averaging 4.5 gpm, with a maximum of 16 gpm. (WO&GCC 2002)

2.3.8.4 Groundwater Quality

Water quality from Fort Union Coals, while varying in concentrations for several parameters, differs very little in overall water type. Figure 2.3.4 portrays groundwater quality graphically from USGS wells in the SHCW in addition to surface water quality values. The diagram shows a grouping of data points in the sodium bicarbonate region of the diagram. Similar to other water co-produced with CBM across the PRB, groundwater from the SHCW is dominated by sodium and bicarbonate.

Table 2.3.7 portrays concentrations of major cations and anions of groundwater in the drainage from six wells completed in Fort Union aquifers, which are the target of CBM activities in the watershed. TDS values from these wells range from 671 to 2,060 mg/l, with an average of 1,517 mg/l. EC values ranges from 1,080 to 3,800 µmhos/cm and average 2,355 µmhos/cm. SAR values for the wells average 25.4 and range from 17.9 to 32. The dominant cation, Sodium (Na) concentrations average 602 mg/l and range from 264 to 800 mg/l.

Table 2.3.7
Spotted Horse Ck. CBM Water Quality[1] (Ft. Union Formation) vs. WDEQ Discharge Standards

Parameter[1]	CBM Water Maximum Concentration	CBM Water Mean Concentration (N=6)	Mean Plus 1 Std. Deviatior (Upper 80% Confidence Level	Mean Plus 2 Std. Deviations (Upper 95% Confidence Leve	WDEQ NPDES Discharge Standard
Conductivity	3800 µmhos/cm	2355 µmhos/cm	3269 µmhos/cm	4182 µmhos/cm	7500 µmhos/cm (stock and wildlife water)
Conductivity	3800 µmhos/cm	2355 µmhos/cm	3269 µmhos/cm	4182 µmhos/cm	2000 µmhos/cm (irrigation)
pH	8.1	7.6	7.9	8.1	6.5 – 8.5
TDS	2060 mg/l	1516 mg/l	2028 mg/l	2539 mg/l	5000 mg/l
Oil & Grease	[2]	[2]	[2]	[2]	10 mg/l
Radium 226	[2]	[2]	[2]	[2]	1 pCi/L
Cl	21 mg/l	13.6 mg/l	18.9 mg/l	24.3 mg/l	46 mg/l
SO_4	24 mg/l	5.6 mg/l	15.1 mg/l	24.7 mg/l	3,000 mg/l
Ca	27 mg/l	20.2 mg/l	27.2 mg/l	34.3 mg/l	N/A
Mg	26 mg/l	14.1 mg/l	21.6 mg/l	29.1 mg/l	N/A
Na	800 mg/l	602 mg/l	803 mg/l	1004 mg/l	N/A
Fe (dissolved)	[2]	[2]	[2]	[2]	0.2997 mg/l
Mn (dissolved)	[2]	[2]	[2]	[2]	0.629 mg/l
As (total)	[2]	[2]	[2]	[2]	0.007 mg/l
Ba (total)	[2]	[2]	[2]	[2]	1.800 mg/l
SAR	32	25.4	31.1	36.7	7.0

[1] Note: values from USGS Open File Report (00-372)
[2] No Data Available

2.3.9 Erosion Potential

Within the SHCW study area, soils susceptibility to water erosion is generally moderate in the subsurface topsoil horizon and moderate to severe in the subsoil horizons due to clay content, low permeability and non-cohesive soils, as well as steep slopes. These soils may represent 66 percent of the drainage area. Average runoff potential is moderate to high. Overall wind erosion potential is low to moderate on the soils described above and moderate to high on the sandy and coarse loamy soils in the basin. These soils comprise approximately 34 percent of the basin. (Refer to Section 2.3.5 for further descriptions of the SHCW soils.)

Those soils map units in SHCW occurring on steep upland topography include: Unit 330 – Ironbutte – Fairburn – Mittenbutte Complex, Rangeland, 0 to 40% slopes, and Unit 312 – Fairburn – Samsil – Badlands Complex, 25 to 60% slopes. Combined, these soils represent approximately 15% of the drainage. Unit 330 is comprised of coarse loamy textures with moderate to high permeability. The overall erosion potential is moderate, due primarily to the steep slopes associated with this unit. Unit 312 has fine loamy to fine soil textures and the erosion potential is moderate to very high depending on texture, vegetative cover, and slope steepness.

Sideslopes, alluvial fans, terraces, and colluvial deposits in the drainage are occupied by Unit 167 – Jaywest – Moorhead loams, 0 to 6 % slopes and Unit 255 – Ulm-Bidman Complex, 0 to 6% slopes. These soils have fine loamy to fine surface textures, and the erosion potential is moderate to high.

The Spotted Horse Creek floodplain and local terraces are dominated by Map Unit 298 – Haverdad-Boruff Complex, 0 to 6% slopes. The Haverdad soils have soil textures ranging from coarse loamy to fine loamy, and erosion potential is moderately low to moderately high, depending on slope, texture, and vegetative cover. The Boruff soils are fine loamy, and erosion potential is moderate to moderately high. These soils comprise approximately 1.8 percent of the drainage.

High saline and/or sodic soils that are susceptible to surface erosion include: Emigha and sodic-Arvada. While erosion potential is high on these soils, they comprise a small percentage of the drainage basin.

While the above discussion describes the dominant soil units in the drainage, numerous soil map units occur, and an individual assessment of erosion potential should be made by referring to the Map Unit Descriptions in Appendix 1.

2.4 Miscellaneous Description Topics Common to All Watersheds

2.4.1 Climate

The Western Regional Climate Center collects climatological data on two field stations within the Three Horses watersheds: Dead Horse Creek and Echeta 2NW. The Dead Horse Creek field station, as the name implies, is located in the DHCW. The Echeta 2NW field station is located in the WHCW. Additionally, the Climate Center collects data at the Arvada 3N Field Station, which is located between the WHCW and the SHCW.

The location of each of these monitoring stations (in Latitude/Longitude) and pertinent data collected at these stations is summarized in Table 2.4.1.

Table 2.4.1
Climatological Data

Parameter	Dead Horse Ck.	Echeta 2NW	Arvada 3N
Location (Lat/Long)	44°11', 105°55'	44°29', 105°54'	44°42', 106°06'
Elevation (Feet)	4470	4000	3680
Avg. Annual Precipitation (inches)	11.37	15.68	11.55
Average Annual Snowfall (inches)	30.6	55.6	34.41
Average Max. Temp. (July) (°F)	87.0	88.7	90.6
Average Min. Temp. (January) (°F)	7.6	7.2	3.4
Average Last Day of Frost in Spring	May 15	May 10	April 30
Average First Day of Frost in Fall	October 2	October 2	October 2

Typically, over 60% of the annual precipitation at these field stations falls between March and July as either rain or snow, and more than 30% of the snow is reported during the months of March and April.

2.4.2 Demographics and Land Use

2.4.2.1 Population

There are no incorporated towns or cities within any of the Three Horses drainages. While there was no tabulation of actual residences within the Three Horses watersheds, it is estimated that they number less than 25.

2.4.2.2 Transportation

U.S. Highway 14-16 traverses through the WHCW for approximately eight miles and through the SHCW for approximately 12 miles. I-90 parallels Dead Horse Creek for approximately 11 miles from its confluence with the Powder River, and the Burlington Northern Santa Fe Railroad parallels Wild Horse Creek throughout much of its length.

Approximately 150 miles of county roads pass through and serve the three watersheds. There are no public railroads, airports or other mass transit systems located within the three watersheds.

The estimated number of miles of county roads (i.e., not including major highways) within each watershed is listed in Table 2.4.2.

Table 2.4.2
Estimated Number of Miles of County Roads

Watershed	Estimated Number of Miles within Each County		
	Sheridan	Campbell	Johnson
Dead Horse Creek	0	31	2
Wild Horse Creek	18	85	0
Spotted Horse Creek	0	14	0
TOTALS	**18**	**130**	**2**

2.4.2.3 Employment and Education

The history of employment within the Three Horses drainage areas has primarily been in agriculture. However, over the last few years, there has been a rapid rise in employment relating to CBM construction and operations.

There are no schools within the Three Horses drainage areas. Students attend school in either Buffalo (Johnson Co.), Arvada (Sheridan Co.), Clearmont (Sheridan Co.) or Gillette (Campbell Co.), depending upon the county in which they live. Both Sheridan and Gillette have two-year community college campuses.

2.4.2.4 Zoning

There is no zoning in Campbell County within the area of the DHCW, nor is there any zoning in Campbell County within the area of the DHCW, WHCW and SHCW. All lands within Sheridan County that are within the WHCW and SHCW are zoned agricultural.

2.4.2.5 Residential Land Use

As mentioned previously, there are no incorporated towns within any of the three watersheds, and there are also no post offices. The following small, unincorporated locales exist within the Three Horses areas:

- Croton (WHCW)
- Spotted Horses (SHCW).

2.4.2.6 Agricultural Land Use

Almost all of the land use within the Three Horses drainages is agricultural, and most of that agricultural activity is livestock (cattle) ranching. Minor amounts of existing irrigated cropland in this area are used to cultivate hay, which is used to feed area livestock, and some non-irrigated acreage is used in the production of small grains such as wheat, barley and millet.

2.4.2.7 Industrial Land Use

In addition to CBM development, sand and gravel mining is another small industry existing within the Three Horses drainage areas. The Land Quality Division of the WDEQ monitors eight active surface mining sites within the WHCW and SCHW, all in Campbell County. Table 2.4.3 includes the mining sites' permittees, locations, minerals mined and sizes of disturbed areas. All of the sites are permitted under WDEQ's ten-acre exemption regulations for very small mining operations.

Table 2.4.3
Active Surface Mining Sites

Watershed	County	Permittee	WDEQ Permit No.	Location (S, T, R)	Mineral(s)	Active Area (acres)
Wild Horse	Campbell	Campbell Co. R&B	PT348C	26,49,74	Scoria	2
	Campbell	Timber Jack Joe	833-ET	9,49,74	Scoria	1
	Campbell	Kennedy Oil	1130-ET	33,50,73	Scoria	3
	Campbell	Campbell Co. R&B	PT348C	6,52,75	Scoria	5
Spotted Horse	Campbell	Werner Land Corp.	1123-ET	23,55,75	Scoria	4
	Campbell	Carson	1183-ET	22,55,75	Scoria	10
	Campbell	Duane Odegard	1161-ET	9,55,75	Scoria	5
	Campbell	Campbell Co. R&B	PT348C	9,55,75	Scoria	10

2.4.3 Stream Classifications

The WDEQ has recently classified many of the streams and tributaries within the Three Horses watershed areas. Those streams and tributaries to those streams are listed in Table 2.4.4.

Table 2.4.4
WDEQ Classified Streams and Tributaries

Watershed	Tributary
Dead Horse Creek	North Prong Dead Horse Creek
Wild Horse Creek	North Prong Wild Horse Creek
	Middle Prong Wild Horse Creek
	Twenty Mile Creek
	Beke Bridge Draw
	South Draw
	North Draw
	Kingsbury Creek
Spotted Horse Creek	Southwest Draw

All of the above listed streams and tributaries have been classified as 3B. A 3B stream is defined in WDEQ's Chapter 1 of its Rules and Regulations for water quality as follows:

> "Class 3B waters are tributary waters including adjacent wetlands that are not known to support fish populations or drinking water supplies and where those uses are not attainable. Class 3B waters are intermittent and ephemeral streams with sufficient hydrology to normally support and sustain communities of aquatic life, including invertebrates, amphibians, or other flora and fauna which inhabit waters of the state at some stage of their life cycles. In general, 3B waters are characterized by frequent linear wetland occurrences or impoundments within or adjacent to the stream channel over its entire length."

The Powder River has been classified by WDEQ as being a 2ABWW stream, which is defined in Chapter 1 of WDEQ's Water Quality Rules and Regulations as follows:

> "Class 2AB waters are those known to support game fish populations or spawning and nursery areas at least seasonally and all their perennial tributaries and adjacent wetlands and where a game fishery and drinking water use is otherwise attainable. Class 2AB waters include all permanent and seasonal game fisheries and can be either "cold water" or "warm water" depending upon the predominance of cold water or warm water species present. Unless it is shown otherwise 2AB waters are presumed to have sufficient water quality and quantity to support drinking water supplies and are protected for that use. Class 2AB waters are also protected for nongame fisheries, fish consumption, aquatic life other than fish, primary contact recreation, wildlife, industry, agriculture and scenic value uses." (WDEQ 2002)

2.4.4 Game Animals

Game animals in the Three Horses watershed areas include pronghorn (*Antilocapra americana*), mule deer (*Odocoileus hemionus*), and white-tailed deer (*Odocoileus virginianus*). Elk (*Cervus elaphus*) inhabit portions of the WHCW. Upland game birds in the area include ring-necked pheasant (*Phasianus colchicus*), gray partridge (*Perdix perdix*), blue grouse (*Dendragapus obscurus*), wild turkey (*Meleagris gallopavo*), mourning dove (*Zenaida macroura*), sage grouse (*Cenrocercus urophasianus*), and sharp-tailed grouse (*Tympanuchus phasianellus*). (U.S. Department of Interior, BLM, 2002)

Numerous nongame animals exist within the Three Horses watershed areas, but their identification is not included within this study.

2.4.5 Special Status Flora and Fauna Species

Several flora and fauna species that may possibly occur within the Three Horses drainage areas have been afforded special status by federal and state agencies, including the U.S. Fish and Wildlife Service (USFWS), the United States Forest Service (USFS), BLM and the WGFD. (U.S. Department of Interior, BLM 2002) Special status designations include:

- Threatened and endangered species as listed by USFWS,
- Sensitive species as listed by the BLM and USFS, and
- Special concern species as categorized by WGFD.

A listing of flora and fauna species that are included within these designations and that may exist within the subject drainage areas follows:

Special Status Flora Species

Ute ladies'-tresses Orchid

Special Status Fauna Species

Black-tailed Prairie Dog
Bald eagle
Mountain Plover
Dwarf Shrew
Long-eared Myotis
Fringed Myotis
Townsend's Big-eared Bat
White-tailed Prairie Dog
Swift Fox
Least Weasel
American Peregrine Falcon
American Bettern
White-faced Ibis
Northern Goshawk
Merlin
Upland Sandpiper
Long-billed Curlew
Yellow-billed Cuckoo
Burrowing Owl
Lesis' Woodpecker
Three-toed Woodpecker
Loggerhead Shrike
Golden-crowned Kinglet
Pygmy Nuthatch
Sage Thrusher
Sage Sparrow
Baird's Sparrow
Brewer's Sparrow
Northern Leopard Frog
Columbia Spotted Frog
Milk Snake
Grasshopper Sparrow

2.4.6 Recreation

Hunting is the primary recreational activity within the Three Horses watersheds. Public access to state and federal lands affords opportunities to the general public where privately-held lands cannot be accessed. Game animals listed in Section 2.4.3 are popular pursuits.

Very little other recreational activity occurs related to the Three Horses watersheds. There are no public parks within the drainage areas.

3. COAL BED METHANE IMPACTS

3.1 General

There has been a great deal of discussion and controversy surrounding the CBM play in Wyoming, especially within the PRB. The Three Horses drainage areas are all directly within the areas potentially affected by this play. To examine various water management techniques in the context of CBM development and to understand the need for water management, an understanding of the potential effects and impacts - both positive and negative - is necessary. This report is not intended to provide a comprehensive assessment of potential CBM development effects; however, this section identifies potential effects/impacts within those drainage areas that may result from both existing and future CBM activities. Decisions regarding the implementation of water management techniques should take into account both the potential positive and negative aspects of CBM development. The production of water from the dewatering of coal aquifers may provide opportunity for beneficial water use, and at the same time may result in undesirable discharges. How water is managed may make the difference between these two outcomes.

3.2 CBM Well Permits

There has been a rapid increase in the number of permits each year for CBM wells statewide. Figure 3.1 graphically depicts the locations for the permits issued by the WO&GCC for CBM development as of June 2002 within the Three Horses watersheds. (WO&GCC 2002)

3.3 Vegetation

Sections 2.1.6 , 2.2.6 and 2.3.6 discussed the vegetation characteristics of the three watersheds that comprise the Three Horses areas. As a result of CBM activity, vegetation will be disturbed from site access roads, well-drilling activities, pipeline construction and possibly water erosion. However, if CBM operators maintain best management practices, vegetation effects in upland areas can be temporary. Such practices include:

- careful management of topsoil, so that it can be replaced and utilized as suitable seedbed for revegetation activities;
- reseeding of acceptable grasses, along with nutrients that will allow for suitable regrowth;
- spraying for weeds during the time of disturbance and revegetation of acceptable grasses;
- placement of water bars and similar erosion control devices to minimize the amount of topsoil that is eroded; and
- minimizing the amount of disturbed lands at well pads and along roads constructed for CBM activities.

Areas where vegetation is likely to change will be in those locations where CBM water is allowed to be discharged to channels in the watersheds, or beneath constructed reservoirs that experience continual seepage. Native grasses in these areas are likely to be replaced with wetland species such as Foxtail Barley (*Hordeum Jubatum*) and sedges (*Carex*).

3.4 Roads

Existing public roads have and may continue to see a rapid increase in the amount of usage due to CBM activities. Not only do these roads allow for the transportation of equipment for the construction of wells and pipelines, but also each well and certain pipeline control devices must be periodically visited for operation and maintenance purposes.

CBM activities have impacted these roads in two major ways. First of all, the increase in usage of the roads will prematurely require the installation of gravel on these roads as the base material breaks down, particularly those with scoria used as the roadbase material. Secondly, increased usage causes additional dust and particulates to become airborne, especially during the dry summer months. In some instances, the CBM companies themselves have assisted with the upgrading and maintenance of roads, providing equipment and financing as well as on-going maintenance to assure that they can achieve all-weather access to their facilities. The residents of these areas may benefit from such road work.

3.5 Pipelines

Pipelines are being constructed as part of CBM activities for three principal purposes:

- to gather and convey produced gas from individual wells to compressor stations;
- to convey CBM-produced water to points of discharge as authorized by the WDEQ; and
- to convey produced CBM from compressor stations to market via large transmission pipelines.

Figure 3.2 portrays large natural gas transmission pipelines within or in the vicinity of the Three Horses area. These transmission pipelines are a critical component of the CBM gas production process, because without these transmission pipelines, the gas cannot be conveyed to market. One of the principal reasons that CBM activities have become so prominent in the area south of Gillette in Campbell County is due to the existence of a proliferation of gas pipelines from previous, non-CBM related oil and gas production, allowing for the delivery of gas to market.

CBM development may continue to occur in those areas in which access to gas transmission pipelines is available.

3.6 Erosion

Sections 2.1.9, 2.2.9 and 2.3.9 previously discussed the potential for erosion of soils within the Three Horses drainage areas. To summarize, soils in the area are viewed as generally moderate in the subsurface topsoil horizon, and moderate to severe in the subsoil horizons, due to low permeability and the non-cohesiveness of the soils. The relative steepness of the slopes in many areas within the three watersheds can also increase erosion potential. Due to the soil textures and steep topography, erosion is likely to occur in uplands area if CBM water is allowed to be discharged directly to the ground unless erosion control measurers are implemented.

Erosion due to CBM water can be minimized through proper mitigation efforts, and that which occurs on lands disturbed by CBM-related construction can be viewed as only temporary if steps are taken to carefully manage topsoil, reseed and add fertilizer to disturbed areas. Constructing roads with minimal cuts and fills can also minimize erosion, as well as not constructing roads in areas where the steepness of cut-and-fill areas preclude practical revegetation.

The University of Wyoming Civil Engineering Department, in conjunction with the WWDC, has recently developed a model to be used for the prediction of erosion potential in streams due to the introduction of CBM water as an additional water source. (Wilkerson 2002) The model attempts to estimate the percentage of additional channel width that may be necessary to convey forecasted additional flows resulting from CBM discharges.

Representatives of the Civil Engineering Department have recently presented results from use of the erosion potential model for the DHCW. (Wilkerson 2002) The model assumed that 12 gpm would be discharged per CBM well, with a spacing of 40 acres/well site, and that all areas within the DHCW would be occupied CBM wells and producing water simultaneously. Despite these conservative values, the additional channel width required to convey these CBM waters was approximately 10%. Based upon this analysis performed, it appears that CBM waters may contribute only slightly to increased erosion due to discharges flowing down existing main-channel streams.

3.7 Surface Water Quality and Quantity

Undoubtedly the greatest amount of emphasis relating to CBM impacts has to date been placed upon appropriate methods to handle and/or dispose of CBM-produced water. Because of the large number of wells predicted for the PRB in general, and the Three Horses area in particular, a great deal of thought and analysis have been expended to determine the best overall means of handling the produced water.

The amount of water that is and may eventually be produced as a result of CBM activities is generally a function of:

- the number of wells that are drilled and operated for the purpose of producing CBM,
- the number of formations producing CBM and resulting water,
- the formation within which the wells are drilled and operated, and
- the length of time that the wells are operated.

CBM wells are initially pumped to produce greater yields in order to lower the groundwater to a level that will allow for the coal seam to depressurize, allowing the CBM to release into and up the well to a point of collection. Once the aquifer is dewatered to a point that allows CBM to flow up the well, water is pumped at a decreased flow rate. Steady-state groundwater pumping often occurs after one year of commencement of initial pumping.

Water quality from CBM production activities varies and is primarily a function of:

- the formation from which the water is produced, and
- the geographical surface location from where the water was produced.

The two parameters that have been the principal focus of CBM water quality are TDS and SAR, although, because of the interrelationship of TDS and EC (both measure to some degree the total amount of dissolved solids in water; i.e., salinity), EC is oftentimes used as a surrogate for TDS due to the ease with which can be measured. SAR is a calculated ratio of soluble sodium to soluble calcium and magnesium. SAR theory assumes that the soluble cations in the soil solution are in equilibrium with adsorbed cations and thus can be empirically related to exchangeable sodium. SAR is calculated as follows:

$$SAR = Na^{+}{}_{S} / (Ca^{++}{}_{S} + Mg^{++}{}_{S})^{-2} /2,$$

where $Na^{+}{}_{S}$, $Ca^{++}{}_{S}$, and $Mg^{++}{}_{S}$ = soluble sodium, calcium, and magnesium, respectively.

Both EC (or TDS) and SAR are important parameters in the analysis to determine the acceptability of water for irrigation purposes. Salinity as measured by TDS or EC can affect crop water availability. If the total quantity of salinity in the irrigation water is high enough that salts accumulate in the crop root zone or on the plant, crop growth and yield can be affected. Where excessive soluble salts accumulate in the root zone, plants have increasing difficulty in extracting water from the soil profile. Reduced water uptake by the plant can result in slow or reduced growth. Different varieties of crops have different salinity tolerance levels. (NRCS 1997)

SAR, in conjunction with TDS or EC, is a measurement of the sodium hazard of a particular water. It can be utilized to determine the water infiltration rate of the soil. Permeability problems occur when the soil or the irrigation water is relatively high in sodium and low in calcium, thus the calculation of SAR is based upon the relationship of these three cations. (NRCS 1997)

From a soil infiltration (or permeability) standpoint, the relationship between salinity and SAR is such that the higher the salinity of a water or soil, the higher the SAR can be without negatively impacting the infiltration capability of the soil. (NRCS 1997) Correspondingly, by adding calcium or magnesium to a water or soil, the impacts to infiltration can be negated, although such chemical addition will likely increase salinity values and thus could conceivably exacerbate problems affecting crop water availability associated with high salinity values as described above.

Even though there is a link between salinity and SAR, WDEQ has established individual, distinct concentration limits on both TDS and SAR for groundwater to be utilized for agricultural purposes. (WDEQ 1980) These two values and their concentration limits are as follows:

- TDS – 2000 mg/l, and
- SAR – 8.

In issuing permits for discharge of CBM water directly onto the land surface where the possibility for use for irrigation exists, WDEQ is currently utilizing the following limits for EC and SAR within the Three Horses basins:

- EC - 2000 μmhos/cm, and
- SAR - 6.0 (except for lower areas of WHCW, in which the SAR may not exceed 11.0).

Other constituents sometimes existing in CBM-produced water that have occasionally been sources of concern have included:

- Manganese,
- Barium,
- Radionuclides, and
- Iron.

Because the concentration of the above four constituents have to date not generally been seen in the limited number of water samples from the Three Horses drainage areas as a potential cause of significant water quality degradation, this report will principally focus upon SAR and EC (or TDS). Additionally, because sodium is the principal cation of interest in the calculation of SAR, it will also be used as a tool for purposes of analysis and discussion on methods that can be employed to address water quality-related CBM impacts.

Sections 2.1.8.3, 2.2.8.3 and 2.3.8.3 provided data collected within the Three Horses drainage areas from coal seams beneath the ground surface that are the target of CBM activities. Portions of this data are again depicted in Table 3.2.1. This table portrays representative water quality values for TDS and SAR in relation to the coal seams from which groundwater was extracted, with the coal seams shown in the order of increasing depth. The number of reported results in certain coal seams is limited.

Table 3.2.1
Coal Seam Water Quality Representative Values

Coal Seam	Number of Reported Results	Mean EC (μmhos/cm)	Mean SAR
Wyodak	13	999	6.8
Anderson	18	1274	11.0
Canyon	6	1493	15.7
Cook	2	2335	27.0
Wall	2	1935	21.2
Pawnee	2	860	10.7
Big George	1	3020	29.0

3.8 Groundwater Quality and Quantity

The WSEO has ruled that the production of water in order to capture CBM is a beneficial use of Wyoming's groundwater resources. As such, CBM activities have been permitted to withdraw groundwater from the applicable coal-bearing formations that contain CBM for the purpose of gas production.

The actual quality of the produced groundwater has been discussed in previous sections. To date, it is unknown if continued withdrawal of groundwater will degrade the quality of the groundwater remaining in the aquifer. However, if CBM-produced water is injected back into the subsurface, there is the potential for possible effects upon existing groundwater quality. This potential will be discussed more extensively in Section 4, in which the water management alternative of injection is more fully explored.

The U.S. Department of Interior, BLM's draft environmental impact statement for the PRB makes the following predictions regarding groundwater quantity within the Fort Union Formation as a result of CBM operations in the PRB, assuming full development is allowed to take place.

- Maximum projected drawdowns would occur in the centers of CBM development. Drawdown would depend upon the depth of the target coal seams below the surface.
- Drawdowns could approach 500-700 feet BLS in the DHCW and WHCW; drawdowns in the SHCW would be less and on the order of 200-300 feet.
- Once CBM water production starts to decline, recovery of water levels in the coal seams would begin to become apparent. In ten to fifteen years, water levels will recover to 75-80% of pre-operation levels. The recovery would be due primarily to redistribution of groundwater stored in the aquifer, as groundwater stored outside the area of CBM development would resaturate and repressurize the areas that were depressurized during CBM activities.
- Complete water level recovery would be a very long-term process (95% recovery over the next one hundred years) and would be the result of leakage from overlying and underlying sand and undeveloped coal units. These units would in turn be recharged from surface infiltration. Due to large expected drawdowns, the DHCW and WHCW areas would be particularly slow to fully recharge. (U.S. Department of Interior, BLM 2002)

Due to the expected large drawdowns in the DHCW and WHCW discussed above (and to a lesser extent the expected drawdown in the SHCW), it is anticipated that many of the existing domestic and stockwater wells may be affected by the CBM activities. Standard water well agreements currently in place routinely require the CBM operators to monitor groundwater levels, and if existing wells are found to no longer be usable, the CBM companies are required to drill new wells into deeper water-bearing formations not anticipated to be affected by their activities.

3.9 Historical Agricultural Practices

Because almost all of the lands affected by CBM development are agricultural-related, it may be assumed that historical agricultural practices may be affected by CBM development. Both advantages (or benefits) and disadvantages (or detriments) are likely to occur or have already occurred with the development to date. Those advantages and disadvantages are listed below.

Advantages/Benefits

- Supplementing livestock and wildlife water supplies through creation of stockwater ponds and discharge into streams that were former ephemeral but are now perennial
- Creation of wildlife habitat at stockwater ponds and in newly created riparian habitats
- Possible source of irrigation water (if water quality is acceptable or can be adjusted to be acceptable)
- More roads for ranching access

- If the rancher is the mineral leaseholder, enhanced revenues for ranch properties
- Creation of increased forage along stream banks due to presence of CBM produced water

Disadvantages/Detriments

- Temporary disturbances due to pipeline and road construction, resulting in forage losses and opportunities for weed growth
- Newly created vegetation along streambanks may not be suitable for forage
- Access problems across previously dry streams by both rancher and livestock
- Increased amounts of ice buildup during winter
- Impact upon historical precipitation runoff flows due to new dam and reservoir construction
- Potential for perennial water in low areas behind spreader dikes or in areas where cattle have historically wintered or calved
- CBM produced water may not be suitable for irrigation and may instead impact soil permeability or existing vegetation

4. WATERSHED MANAGEMENT ALTERNATIVES

The previous section provided a summary of potential or existing CBM impacts within the Three Horses watersheds. Many of the impacts are minor in scope, are temporary and can be successfully mitigated with existing resources, cooperation and common sense. That is not necessarily the case, however, with the impacts due to CBM-produced water discharges. This area is one in which proper planning must be attempted in order to provide maximum coordination among local landowners, CBM operators, public officials, and the states of Montana and Wyoming. Only by successfully addressing the concerns and problems expressed by all of these parties associated with water discharges can reasonable solutions move forward. As a result, this section is devoted to a review and discussion of various watershed management alternatives that will address the water situation.

Several of the alternatives require that the quantity of CBM water produced basinwide be determined for the purpose of determining that alternative's viability. In order to obtain a reasonable figure for this quantity of water, discussions were held with CBM operators, regulatory agencies and representatives of the Coal Bed Methane Coordination Coalition. Factors that affect the quantity of water produced include:

- the amount of time that the well has produced water;
- the coal seam in which the well is located;
- the physical properties of the aquifer;
- the number of wells producing water;
- the spacing of the wells;
- the number of coal seams producing water; and
- the location of the well with respect to other producing wells.

After discussions were held and information evaluated, it was decided that the following assumptions would be used to forecast the amount of water that will be produced.

- Wells are spaced at 80 acres.
- Each well produces eight gpm.
- Two coal seams are tapped at the 80-acre spacing.

It has been reported that, with time, flows have decreased to closer to five gpm. (Likwartz 2002) As such, the eight gpm figure may be overly conservative. However, initial pumping rates have been shown to be considerably greater, and eight gpm was believed to be a reasonable number given the fact that new wells are coming online continually.

In order to forecast the water production, it is also assumed that there is full development throughout the Three Horses watershed, and that this development occurs simultaneously so that all wells are pumping at the same time. Such a scenario may indeed be a maximum case estimate. However, should natural gas prices escalate significantly, CBM development may increase considerably above current levels, and with it the need to effectively manage produced water may become even more important.

In describing and outlining the viability of each water management alternative, the following information is provided as a tool for comparison purposes:

- a description of the management alternative;
- the purpose and principles of that particular alternative;
- the design criteria that would have to be followed in order to implement the alternative;
- the benefits and/or advantages gained in implementing the alternative;
- the detriments and/or disadvantages inherent to the alternative
- any permitting and/or regulatory requirements that would have to be addressed in order to implement the alternative; and
- cost estimates to implement the alternative, portrayed on a cost-per-1000 gallons basis.

In order to develop the cost per 1000 gallons for water management facilities that will have an extended life, an annualized rate of return must be used for cost comparison purposes. It is assumed that the annualized rate of return is 4% for a term of 20 years. While some may question amortizing facilities for a twenty-year period when some wells' life expectancy would be considerably less than this length of time, the fact that multiple coal seams may be tapped at one site and continue to utilize the water management facilities leads to the conclusion that the 4% @ 20 year figure is reasonable.

Included within this section are brief descriptions of various alternatives to address the issues surrounding the production of water from CBM operations in the Three Horses drainages. Some of these alternatives may be more applicable in one of the drainages than in the other two; i.e., injection or land application. However, no cost differentiation has been assumed relative to the specificity of the respective watershed.

It is important to recognize in the review of the cost comparison figures that they represent merely gross conceptual estimates on various water management alternatives at a reconnaissance level as intended by the scope of this study. Actual costs for implementation could vary considerably from those portrayed in this section. Still, these figures represent a means with which to compare the various water management alternatives.

4.1 Direct Discharge to Channels

4.1.1 General Description

The water management alternative initially employed in the PRB and throughout northeastern Wyoming for most operators outside the PRB has been the direct discharge of CBM water to channels. In most cases, the discharge is collected from a well(s) and released at outfalls utilizing culverts, pre-cast concrete energy dissipaters, or stockwater tanks. As of August 2002, a total of 89 NPDES discharge permits have been issued within the three drainages:

- 11 in DHCW,
- 59 in WHCW, and
- 19 in SHCW.

These permits include those authorized for direct discharge to the surface as well as for discharge to full containment facilities. (WDEQ 2002)

4.1.2 Purpose and Principles of Operation

Direct discharge allows convenient release of produced water at locations beneficial to operators and landowners. Utilization of small stockwater tanks with overflows provides valuable water sources for both livestock and wildlife.

4.1.3 Application Criteria

Situations where direct discharge is most applicable include:

- landowner preferences for supplementing livestock water sources,
- water quality and quantity are compatible with channel size, morphology and soil types, and
- evaporation, evapotranspiration (ET) and infiltration negate any downstream implications.

4.1.4 Design Criteria

The list below outlines design factors to keep in mind when reviewing the potential to utilize direct discharge as a water management alternative.

- Maximum discharge rate (operator estimates range from 40-240 gpm at startup to less than 10 gpm within one year).
- Location of outfall or tank — distance to nearest channel and the channel's gradient.
- Distance to main channel and potential to reach downstream irrigators or the Powder River.
- Potential vegetation and soil implications.
- Impacts to downstream channel crossings, reservoirs, etc.
- Evaporation, infiltration rates.
- Long-term use by landowner, potential to utilize resource beyond CBM production cycle.

Increased scrutiny in terms of water discharges and the potential to reach downstream irrigators, as well as the Powder River, creates the necessity for extra measures in terms of analysis. Specifically, future permittees may want to examine the inclusion of compliance points upstream of any irrigation and utilize runoff water quality data to perform mass balance or mixing calculations for intermingled waters. Site-specific locations for discharges may also need to be addressed; soils with moderate to high permeabilities could provide increased infiltration and potentially avoid controversial soil impact issues (see Soils section for more details). Additional analysis based upon observed infiltration and evaporation rates in the drainage may reinforce consumption values utilized in the permitting process.

4.1.5 Advantages/Benefits

Benefits of direct discharge are:

- cost effectiveness,
- supplementing livestock and wildlife water supplies,
- creation of wildlife habitat,
- recharging shallow and possibly deeper aquifers,
- the potential to increase forage production, and
- the possibility that much of the actual flow discharged will be lost to evaporation and infiltration, replenishing the shallow water-bearing aquifers and greatly diminishing the amount of water to ultimately reach the Powder River. (Meyer 2000 and Applied Hydrology Associates 2001)

4.1.6 Disadvantages/Detriments

Disadvantages to this technique include:

- the metamorphosis of a system from ephemeral or intermittent to perennial,
- vegetation changes, including the potential to decrease forage production,
- access problems resulting from inadequate infrastructure such as culverts, low water crossings, bridges, trails, etc.,
- increased amounts of ice buildup during winter,
- potential for perennial water in low areas behind spreader dikes,
- potentially more active headcutting/erosion and subsequent deposition, leading to increased over-banking,
- the potential for decreased soil permeability with the change in surface water quality, and
- the possibility that downstream landowners will consider CBM surface flow across their lands as a trespass.

4.1.7 Permitting and Regulatory Requirements

Table 4.1.1 outlines water quality limits established by WDEQ for selected areas of concern in the DHCW. These limits have been derived by WDEQ utilizing its Water Quality Rules and Regulations, including specifically the anti-degradation clause in Chapter 1 of these same rules and regulations. (Hargett 2002)

Table 4.1.1
WDEQ Discharge Standards

Parameter	WDEQ NPDES Discharge Standards
EC (stock and wildlife water)	7500 umhos/cm
EC (irrigation)	2000 umhos/cm
pH	6.5 – 8.5
TDS	5000 mg/L
Oil & Grease	10 mg/L
Radium 226	1 pCi/L
Cl	46 mg/L
SO_4	3,000 mg/L
Ca	N/A
Mg	N/A
Na	N/A
Fe (dissolved)	0.2997 mg/L
Mn (dissolved)	0.629 mg/L
As(total)*	0.007 mg/L
Ba(total)*	1.800 mg/L
SAR (irrigation)	6(DHCW), 6(upper areas WHCW), 11(lower areas WHCW), 6(SHCW)

*Hargett & Thomas, 2002

4.1.8 Cost Estimates

Table 4.1.2 outlines capital cost estimates for direct discharge. Notice that the cost estimate does not include the cost of piping the water to the discharge point. This value is highly dependent upon the distance to the point of discharge, the number of wells and the desired location for discharge. This estimate assumes that four wells are connected to each discharge facility location.

Table 4.1.2
Capital Cost Estimate for Direct Discharge

Item	Unit	Quantity	Unit Cost	Cost	Cost
Preparation of Final Designs & Specs					$875
Permitting and Mitigation					$500
Legal Fees					n/a
Acquisition of Access & ROW					n/a
Construction and Materials Costs					
Outfall Device (tank)	LS	1	$5,000	$5,000	
Gravel	TN	5	$20	$100	
Concrete	CY	5	$100	$500	
Sealing Materials	LS	1	$50	$50	
Winterizing of tank (propane heater, etc)	LS	1	$500	$500	
Overflow Piping	FT	100	$6.0	$600	
Reclamation (material and labor)	LS	1	$2,000	$2,000	
Construction Cost Subtotal				**$8,750**	
Contingency @ 15%				$1,313	
Construction Cost Total				**$10,063**	**$10,063**
Project Cost Total					**$11,438**

Annual operation and maintenance costs are negligible under this management alternative.

Annualized capital cost: 4% @ 20 years = $11,438 x 0.07358 = $842/year.

Cost per 1000 gal of water = $842 per year/ (8 gpm/well x 4 wells x 1440 min/day x 365 days/year)

= $0.05/1000 gal.

4.2 Containment-and-Loss Reservoirs

4.2.1 General Description

Total containment in off-channel constructed reservoirs has been utilized at various locations in the PRB, as well as throughout the Three Horses watersheds. This type of system employs reservoirs built away from drainage channels and relies upon evaporation and infiltration to decrease water quantities. As a result, these impoundments are built for 100% retention (i.e.: zero surface discharge), and instead rely upon infiltration into the subsurface and evaporation as means to dissipate the CBM water.

4.2.2 Purpose and Principles of Operation

The purpose of the containment-and-loss management alternative is to provide a place to store and dispose of CBM-produced water where other alternatives are less suitable or cannot be implemented. This alternative negates the need for addressing downstream discharge, as there is no discharge required. Once constructed, the containment impoundment receives the pumped water from the CBM wells via pipeline, while infiltration into soils/shallow bedrock and evaporative losses provide the means to dissipate the water. These two loss mechanisms provide the offset to the inflow such that a balance is achieved between the influent volume and the losses. If the water balance is not correct, either the reservoir will remain quite low in water volume or the reservoir will become filled and render it incapable for accepting additional water.

Reservoirs are not constructed within a drainage channel and, as such, are not required to have bypass or outlet facilities.

4.2.3 Application Criteria

This water management alternative is most applicable under the following circumstances:

- water quality precludes direct discharge to receiving stream;
- water quality or season precludes land application/irrigation;
- discharge permit limitations prohibit direct discharge;
- interruption of downstream water rights preclude on-channel impoundment;
- relatively small volumes/rates of CBM water are produced, limiting the size of the reservoir necessary as determined by water balance computations and topography; and
- landowner need for livestock water.

4.2.4 Design Criteria

A number of factors must be examined for successful off-channel total containment. These include the following:

- maximum, minimum and average discharge rate;
- soils;
- topography;
- maximum pond size;
- storm surge;
- unconsolidated, near-surface bedrock geology;
- proximity to flood plain;
- proximity to surface stream;
- cut-fill earthwork volumes;
- evaporation, infiltration computations; and
- soil suitability for embankment construction.

Additionally, down-gradient inspections, monitoring and potentially shallow piezometric wells could be utilized along with staff gauges to monitor levels in the impoundment. Furthermore, it is suggested that emergency outlet works be included in the designs, even though any discharge from the facility will be in violation of the permit.

This management alternative requires construction in "upland areas, outside of natural drainages and alluvial deposits associated with these natural drainages", (WDEQ 2002) as well as relatively broad, flat and concave areas. Erosion control measures at the outlet pipe are recommended as well. Water quality and quantity monitoring requirements are outlined in the guidelines for *Authorization to Discharge Produced Water From Coal Bed Methane Wells Into Off-Channel Containment Units or Class 4C Waters*, approved by WDEQ in April 2002. (WDEQ 2002)

Beyond the above listing, three specific design criteria for off-channel ponds exist:

1) the structure must accommodate the 100 yr/24 hr storm event (surface area based) in addition to the maximum amount of produced water, thus the permitting process requires a water budget analysis;
2) the applicant must prove that "there is no direct subsurface hydrologic connection to surface waters of the state", and
3) while sizing may be dependent upon topography, increasing the surface area (and decreasing the depth) will allow more infiltration and evaporation.

The second requirement necessitates permeable soils that communicate with permeable bedrock but won't allow the infiltration to sub-irrigate and "daylight" down the drainage, thus producing surface flow. Permeabilities of major soil series were discussed previously in Section 2.6, while bedrock attributes are site-specific.

It is recommended that off-channel structures be placed in areas having moderate to high permeabilities—or, more specifically, locations with fine loamy to coarse loamy soils. This recommendation limits potential areas for construction to less than 20% of the drainage. Soil crusting may prove problematic, but can be overcome with dimpling or slight disturbance to break the crust.

4.2.5 Advantages/Benefits

Benefits to off-channel containment include:

- viability as a (short-term) supply of water for livestock and wildlife;
- no addition of water to surface and subsequent issues;
- if built off-channel, few if any issues with downstream irrigation rights;
- some potential to recharge shallow aquifers; and
- general permits available from WDEQ for off-channel reservoirs.

4.2.6 Disadvantages/Detriments

Shortcomings to this management alternative consist of the following:

- Due to no allowable surface discharge, the containment structure is highly dependent upon topography and permeability of surface units.
- Post-CBM production may necessitate the mitigation of structures and reclamation of land.
- The lands beneath the reservoir may eventually contain a high volume of residuals remaining from the dissolved matter.
- Little to no use after CBM production has ceased unless reclaimed (off-channel only).
- Loss of forage production in area of the containment structure during use and until reclamation is complete.
- Potential exists for CBM water to migrate to impermeable layer, then follow it to surface outcropping.
- Considerable areas of land may be necessary to fully effectuate this method of water disposal.
- Evaporation rates much higher in summer than winter, requiring additional winter storage.

4.2.7 Permitting and Regulatory Requirements

Permitting implications are covered by WDEQ for discharge to off-channel containment structures, and the impoundment structure itself requires a WSEO permit. Similar to any permitted outfall, WDEQ water quality standards for livestock and wildlife suitability must be met. WO&GCC requires permits to construct containment pits that include a mitigation plan for post-use. Permits from the BLM on federal lands may also be necessary.

4.2.8 Cost Estimates

Table 4.2.1 below summarizes estimated capital costs for off-channel total containment facilities. These costs do not include piping the water to the structure; these costs vary considerably due to distances and pipe sizes involved. The following assumptions are made in preparing this cost estimate.

- WSEO information indicates that typical off-channel pits are less than 20 acre-feet in size and cannot have a dam structure that exceeds 20 feet in height without significant additional safety measures being implemented. The '20/20' rule decreases costs for filing an application and eliminates a significant amount of paperwork. Therefore, for purposes of sizing a reservoir, the containment reservoir would have a volume of 20 acre-feet, a height of 20 feet, and a surface area of three acres.

- Ten percent of the water that would be stored within the reservoir would be lost to infiltration annually, or two acre-feet. This value would obviously be very site-specific.
- Evaporation losses would be four feet per year. Based upon a surface area of three acres, the volume of water evaporated annually would thus be twelve acre-feet.

Table 4.2.1
Cost Estimate for Containment-and-Loss Reservoir (Off-channel)

Item	Unit	Quantity	Unit Cost	Cost	Cost
Preparation of Final Designs & Specs					$4,000
Permitting and Mitigation					$2,000
Legal Fees					n/a
Acquisition of Access & ROW					n/a
Cost of Construction					
Dam Construction, Excavation	CY	20,000	$2	$40,000	
Water Control Structures	LS	1	$10,000	$10,000	
Outfall (Construction sub-total)	LS	1	$300	$300	
Rock Rip-Rap	CY	10	$50	$500	
Reclamation (material and labor)	LS	1	$5,000	$5,000	
Subtotal				**$55,800**	
Contingency @ 15%				$8,370	
Construction Cost Total				**$64,170**	**$64,170**
Project Cost Total					**$70,170**

Annual operation and maintenance costs are negligible under this management alternative.

Annualized capital cost: 4% @ 20 years = $70,170 x 0.07358 = $5,163/year

Cost per 1000 gal of water = $5,163 per year/ [(2 + 12) A-F/year x 326,000 gallons/A-F]

= $1.13/1000 gallons.

4.3 Containment-and-Release Reservoirs

4.3.1 General Description

This water management alternative is predicated on the assumption that CBM-produced water is not suitable for use as irrigation water; therefore, it can only be discharged down the stream channel during periods when irrigation is not taking place. Under this scenario, water would be stored in containment reservoirs during the irrigation season, and then released during the periods when irrigation does not occur. There would thus likely be minimal impacts upon irrigation within both the Three Horses drainage areas and along the Powder River both in Wyoming and Montana.

4.3.2 Purpose and Principles of Operation

The containment-and-release management option provides an opportunity to greatly reduce the amount of land necessary to contain CBM water in storage reservoirs. Water would be stored from approximately March through October, the period in which irrigation typically occurs. For the interim period between November 1st and March 1st, water could be pumped or released out of the containment reservoirs down the various main channels. By performing such releases, evaporation and infiltration would not have to be utilized as the primary means of disposal of the CBM water, and the majority of the dissolved solids remaining in the reservoirs under the containment-and-loss option could instead be allowed to flow downstream during the non-irrigation period.

The potential for CBM flows to occur during periods of maximum precipitation and associated runoff would be severely decreased, as most such events occur during the late spring and summer months.

4.3.3 Application Criteria

This water management alternative is most applicable under the following circumstances.

- While water would be released from the impoundment reservoirs during the non-irrigation season, it is important to do so when wintertime conditions prevail. Water flowing down channels could possibly freeze as it meanders through the affected valley, eventually forming ice jams that would dam up the water during certain periods. Depending upon the severity of the winter, this could mean that only the months of November and February could be utilized for conveyance of CBM water downstream. If this is the case, it must be recognized that an annual amount of CBM-produced water (less that amount lost during storage due to evaporation and infiltration) would have to be conveyed down the stream during a one-to-two month period. As such, flow rates would conceivably be up to 5-6 times the amount that would flow if CBM-produced water was allowed to flow throughout the year.
- Coordination would have to take place between CBM operators and landowners to make sure that areas that are not channelized (i.e., in areas where water flows over and through grassy meadows) and are also not areas where calving operations have historically occurred. The majority of the three major streams' lengths are channelized throughout must of their length, but smaller, upstream tributaries where stream braiding exists would have to be channelized or piped to a receiving channel.
- Agreement would have to be reached with the State of Montana to allow the possible alteration in the water quality of the Powder River with the addition of the CBM-produced water during the non-irrigation season.
- Any spreader dikes currently in operation would have to be modified to make sure that CBM-produced water flows around these dams unimpeded. In this way, the areas behind these dams would not be flooded. Spreader dikes exist along many of the lower reaches of the main stems of the three drainages.

4.3.4 Design Criteria

A number of factors must be examined for successful off-channel total containment.

- All factors inherent with the containment-and-loss alternative regarding dams and reservoirs must be similarly addressed. Sizes of reservoirs, however, will decrease, as the reservoirs' volumes (and thus amounts of land affected) must only store CBM-produced water during the irrigation season and winter period (when the potential for ice formation precludes releases) vs. storing indefinitely and relying upon evaporation and infiltration for water disposal.
- Soils (both to determine infiltration capacity and potential erosion due to releases down the channel).
- Topography.
- Channel morphology and structure.

4.3.5 Advantages/Benefits

Benefits to containment and release include:

- relatively cost-effective;
- minimal impact upon existing irrigation, both in the Three Horses drainage areas and along the Powder River in both Wyoming and Montana;
- opportunities afforded to periodically discharge accumulated dissolved material within the containment reservoirs downstream;
- viability as a (short-term) supply of water for livestock and wildlife;
- evaporation during the summer months can assist with water dissipation; and
- some potential to recharge shallow aquifers.

4.3.6 Disadvantages/Detriments

Shortcomings to this management alternative consist of:

- water contained within the reservoirs will have constituents at higher concentrations than CBM-produced water due to evaporation taking place;
- potential for limited discharge, thus containment structure is highly dependent on topography and permeability of surface units;
- no assurance that the State of Montana will agree to releases during non-irrigation season;
- potential for increased erosion due to large releases over relatively short period of time;
- potential for damage to existing soils due to spillage out of channels during periods of release, caused by either lack of channel capacity or ice jams;
- post-CBM production may necessitate the mitigation of reservoir areas; and
- drained-down reservoir areas lacking in vegetation will exist during periods after releases and prior to refilling.

4.3.7 Permitting and Regulatory Requirements

- WSEO – dam construction permit
- WDEQ – NPDES discharge permits
- WDEQ - water quality standards for storage of water and seasonal release for livestock and wildlife suitability
- State of Montana – agreement to release water into Powder River during non-irrigation season
- BLM – discharge of CBM-produced waters through downstream federal lands
- Private property owners - discharge of CBM-produced waters through private downstream lands.

4.3.8 Cost Estimates

Table 4.3.1 estimates capital costs for this water management alternative. It has similar costs as the previous alternative for dam and reservoir construction. However, due to the annual release of water (and the corresponding reduction of the need for total evaporation and infiltration), the amount of storage necessary is based upon storage of water during an eight-month period (from March through October).

This alternative assumes that the entire volume within the reservoirs would be released annually, and that there is minimal evaporation and infiltration occurring from the reservoirs during the months that the water is stored. The DHCW is used for cost estimating purposes, and it is assumed that there would be comparable costs if this alternative would be implemented in the other two drainages.

In order to determine the total volume that would be released from reservoirs and determine sizing of downstream piping improvements to meet these volumes, the following assumptions are made:

- Containment-and-release dams would be constructed basinwide, as well as piping and channelization along each of the main channels to successfully bypass spreader dikes and convey water downstream without ponding on landowners' property. While the number and size of reservoirs are not estimated, the cost per acre-feet of construction of necessary dams is derived from Table 4.2.1.
- The following amounts of water would be stored basinwide and released during the non-irrigation season:

(8 gpm/well x 2 wells/site x 154 square miles x 640 acre/square mile) / (80 acres/site) x 8 months/year

= 19,712 gpm for 8 months, or a total volume of 21,000 A-F

Table 4.3.1
Capital Cost Estimate for Containment-and-Release Reservoirs

Item	Unit	Qty.	Unit Cost	Cost	Cost
Preparation of Final Designs & Specs					$5,913,000
Permitting and Mitigation					$50,000
Legal Fees					$25,000
Acquisition of Access & ROW					$125,000
Cost of Construction					
Dam Construction Costs ($2,790/A-F x 21,000 A-F)				$58,590,000	
Downstream Channelization and Piping	LF	18,000	$30	$540,000	
Subtotal				**$59,130,000**	
Contingency @ 15%				$8,869,500	
Construction Cost Total				**$67,999,500**	**$67,999,500**
Project Cost Total					**$74,112,500**

Annualized capital cost: 4% @ 20 years = $74,112,500 x 0.07358 = $5,453,198/year

Cost per 1000 gal of water for annualized capital cost
= $5,453,198 per year/(8gpm/well x 2464 wells x 1440 min/day x 365 days/year)

= $0.53/1000 gal

Estimated Annual Operating Costs (required for conducting and monitoring annual releases) = $20,000/year

Cost per 1000 gal of water for operation and maintenance:
= $20,000 per year/ (8 gpm/well x 2464 wells x 1440 min/day x 365 days/year)

= $0.002/1000 gal.

Total cost per 1000 gallons of water = $0.53/1000 gal.

4.4 Injection

4.4.1 General Description

Injection of produced CBM water into the subsurface has been examined by a number of operators and attempted by a few. Results vary, depending in large part upon the receiving aquifer. The following analysis presents the range of issues associated with this water management technique. While location is critical for any number of management alternatives, injection into shallow or deep aquifers requires a very specific set of hydrological circumstances not seen consistently throughout the PRB. These circumstances are particularly important when determining the capability of an aquifer to receive the quantities of water anticipated to be produced in the CBM development.

4.4.2 Purpose and Principles of Operation

Typical approaches to injection have relied upon either re-completing abandoned oil/exploration wells or the drilling of new wells into target aquifers. Reentry into old wells normally requires back-plugging, cement bond logs and re-perforating, whereas new wells require logs on both open holes and CBM holes in addition to perforating targeted zones. Pressure fall-off or integrity testing must be completed for permitting purposes. Shallow injection wells may have open-holed or under-ream type completion vs. perforations, and they would most likely require significantly less surface infrastructure.

Surface injection facilities typically include:

- storage ponds (to remove any solids and for other pre-treatment purposes),
- large injection pumps,
- disinfection facilities for biological water treatment prior to injection, and
- related monitoring equipment for pressure/volume measurements.

4.4.3 Application Criteria

Injection of CBM water is most applicable under the following circumstances:

- complete exhaustion of surface beneficial uses and/or water quality/quantity issues, precluding discharge to the surface;
- suitable receiving aquifer(s) exist in the area (in terms of water quantity, quality and depths);
- previous aquifer(s) depletion exists due to oil/gas production or municipal/industrial extractions;
- very shallow, partially-to-unsaturated systems exist (potentially the Felix or Smith coal seams in the WHCW or the Smith/Swartz seams in the SHCW);
- close proximity and availability of old oil wells/fields providing aquifer feasibility information or possible re-completion for injection well use; and
- potential storage and future retrieval of the resource.

4.4.4 Design Criteria

Design and installation of any injection system is largely dependent upon the depth and quality of the receiving aquifer(s), as well as the quality and quantity of the water to be injected. The list below outlines important design factors for any injection of CBM waters:

- maximum, minimum and average water volume to be injected (cost estimates based on at least 100 gpm or 2.4 barrels/minute);
- water quality of receiving aquifer, water quality of injection water for determination of compatibility, level of pre-treatment and/or anti-scalant(s) necessary;
- fracture pressure of receiving aquifer;
- availability of power;

- if re-completing an old well, good quality of lithologic and electrical logs aid suitable aquifer determination; and
- re-completion is also enhanced by good quality casing and cementing.

4.4.5 Advantages/Benefits

The primary benefits of injection lie in the ability of the CBM operators to inject large quantities of water for disposal or possible storage of the groundwater resource for future uses. Benefits of injection depend largely upon the suitability of receiving aquifers. Shallow aquifers (e.g., Wasatch, Fort Union, Lance or Fox Hills) are more likely to allow future recovery of injected water without water quality issues and large expenses.

Several shallow injection wells have been permitted and operated in the WHCW. These wells, completed in the Felix Coal to a maximum depth of 130 feet, have accepted an estimated 10 gpm at no injection pressure. (Wert 2002) Opportunities for injection into the Felix Coal, however, may be limited by formation outcrops in the lower portions of the WHCW valley. Similarly, the Smith Coal, although seeing more intensive CBM development, may provide an additional suitable receiving aquifer if gas production is not apparent. WO&GCC data indicates injection wells have also been completed in the deeper Wall/Pawnee coal formations within the WHCW.

At the time of this report publication, three Class 5C5 injection permits were approved for the SHCW. Several injection permits have been issued in the DHCW, but it is unknown as to whether or not any active injection is occurring at this time. A single well completed in the Fox Hills has been tested and reportedly took 22 gpm under unknown pressures. (Olson 2002) At least four Class 5C5 permits have also been issued within the WHCW.

Most operators permitted the injection facilities as a complement to existing water management techniques rather than as a primary method.

4.4.6 Disadvantages/Detriments

Deficiencies observed in injection programs have to date primarily been the overall high costs and the potential for high initial investment without achieving the necessary injection volumes. Even re-completion of a non-producing well can prove problematic due to poor cementing and mud control during previous drilling, as well as poor quality logs in zones not targeted by the initial drilling effort. Finding suitable receiving aquifers has to date proven difficult.

Beyond the lack of suitable aquifers, certain regulatory requirements exist regarding operational procedures. Injection wells are required to be integrity-tested every five years, and the radius of pressure influence must be calculated. Injection pressures cannot exceed the fracture pressure of the receiving aquifer. Decreases in downhole permeability result in higher pressures and additional enhancement costs. Additionally, regulatory language dictates that the receiving water quality "be of similar or lower class of use" than the quality of the water to be injected, creating further difficulty in finding a suitable aquifer. (WDEQ 2001) Water quality compatibility may also become problematic, as brines associated with many Mesozoic oil-producing formations are likely not compatible with water co-produced with CBM extraction (for Class II, UIC wells).

4.4.7 Permitting and Regulatory Requirements

WDEQ permits general underground injection control facilities into Class 5C5 CBM injection wells and facilities into the Wasatch, Fort Union, Lance and Fox Hills Formations. Alternatively, injection into deeper (i.e.; Mesozoic and Paleozoic) units requires a Class II UIC permit from the WO&GCC.

Additional requirements from the WO&GCC in terms of permitting, reporting, pit construction, abandonment, etc. may also apply.

4.4.8 Cost Estimates

Several Lance Formation injection wells have been installed in the PRB with varying amounts of success. Up to 100 gpm of CBM water has reportedly been successfully injected. (Demuth 2002)

Table 4.4.1 below summarizes estimated capital costs of drilling an injection well into the Lance Formation, and Table 4.4.2 projects anticipates operational costs. This unit was used as the most conservative approach to a Class 5C5 permit and should be kept in mind when reviewing the estimated costs for construction and operation. Costs for shallow injection systems will not be addressed in the same level of detail; however, estimates from operators indicate that well installation could be completed for as little as $10,000 to $15,000 per well, depending upon the capability of the aquifer to receive fluids. Operational costs are highly dependent upon the depth and permeability of the receiving aquifer.

Table 4.4.1
Capital Cost Estimate for Injection Well

Item	Unit	Quantity	Unit Cost	Cost	Cost
Preparation of Final Designs & Specs					$70,600
Permitting and Mitigation					$10,000
Legal Fees					$5,000
Acquisition of Access & ROW					$10,000
Well Construction*					
Site Prep/Rig Mobilization/Demobilization	LS	1	$90,000	$90,000	
Drilling Operations	DAY	11	$10,800	$118,800	
Completion Rig Operations	DAY	5	$3,500	$17,500	
Logging, Open Hole, Cased, Cement Bond & Integrity	LS	1	$45,000	$45,000	
Rentals for Completion & Misc.	LS	1	$37,000	$37,000	
Surface Casing (9 5/8")	FT	800	$14	$11,200	
Production Casing (5 1/2")	FT	6,500	$7	$45,500	
Tubing (2 7/8" with coating)	FT	3,600	$4	$14,400	
Cement, Drilling Mud, Completion Fluid	LS	1	$85,000	$85,000	
Bits, Packers and Cross-overs	LS	1	$24,000	$24,000	
Casing Crew & Pick Up/Laydown	LS	1	$7,000	$7,000	
Tanks, Frac Trucks	LS	1	$7,500	$7,500	
Coring and Analysis	LS	1	$30,000	$30,000	
Mudlogger and Drilling Supervision	LS	1	$16,000	$16,000	
Well Construction Subtotal				**$548,900**	
Surface Facilities Construction					
Pond or Water Holding System	LS	1	$25,000	$25,000	
Pipeline	FT	500	$2	$1,000	
Power Infrastructure	LS	1	$25,600	$25,600	
Wellhead Equipment	LS	1	$12,500	$12,500	
Injection Equipment	LS	1	$28,000	$28,000	
Monitoring Equipment	LS	1	$25,000	$25,000	
Disinfection Equipment	LS	1	$25,000	$25,000	
Building	LS	1	$10,000	$10,000	
Reclamation	LS	1	$5,000	$5,000	
Surface Facilities Subtotal				**$157,100**	
Well Construction & Surface Facilities Subtotal				**$706,000**	
Engineering @ 10%				$70,600	
Subtotal #2				$776,600	
Contingency @ 15%				$116,490	
Construction Cost Total				**$893,090**	**$893,090**
Project Cost Total					**$988,690**

*Assumes Lance/Fox Hills completion, does not include piping to holding pond

Annualized capital cost: 4% @ 20 years = $988,690 x 0.07358 = $72,748/year

Table 4.4.2
Operations Cost Estimate for Injection Well

Item	Unit	Quantity	Unit Cost	Cost
Power	KWHRS	156,000	$0.04	$6,240
Maintenance (Labor & Materials)	LS	1	$15,000	$15,000
Reporting/Monitoring	LS	1	$5,000	$5,000
Treatment Consumables (Chlorine, Anti-scalant)	1000 gpm	52,560	$3	$157,680
Integrity Testing (every 5 years after completion)	LS	0.2	$5,000	$1,000
Annual Operational Cost Total				**$184,920**

Total Annual Cost: annualized capital plus operations = $(72,748 + 184,920) = $257,668/year.

Cost per 1000 gal of water = $257,668/ (100 gpm x 1440 min/day x 365 days/year)

= $4.90 /1000 gallons.

4.5 Enhanced Evaporation Using Atomizers

4.5.1 Description

Several operators are currently utilizing enhanced evaporation as a water management tool in the DHCW and WHCW. The primary technique employed to date uses trailer-mounted "atomizers" to distribute the CBM water, evaporating a large percentage of the produced water. Suitable locations require permeable soils, nearby storage facilities and significant research into the compatibility of existing local soils.

4.5.2 Purpose and Principles of Operation

Important seasonal implications exist for this water management technique. Depending upon landowner wishes, March through November are generally the optimal months for utilization of enhanced evaporation. Winter application requires taller towers and can potentially create icy conditions on the surface.

Typical evaporation systems pump water from ponds into and through the towers. The towers are adjusted to obtain maximum air residence time at the optimal distribution rate.

4.5.3 Application Criteria

Conditions conducive to utilization of enhanced evaporation through the use of atomizers are:

- beneficial uses for livestock and wildlife have been exhausted;
- abundant quantities of water normally seen at startup of operations that may decrease with time;
- soil permeabilities in the moderate-to-high range;
- water and soil quality conducive to economical soil mitigation;
- landowner-desired locations for increased forage production;
- thorough research into soil quality at application sites, as well as interaction with non-evaporated water; and
- availability of land for construction of reservoirs to be used for storage and potential removal of iron.

4.5.4 Design Criteria

Similar to many water management techniques, site selection is critical when examining enhanced evaporation. The following list includes key design conditions for utilization of tower atomizers:

- necessary evaporative volumes in the range of 40-70 gpm (per unit);
- extensive research into soils;
- capability of the system to maximize air residence time;
- installation of a monitoring/mitigation system to monitor and maintain soil integrity, as well as to promote plant growth, thereby minimizing potential surface runoff; and
- available power source for pump motors and switchgear.

4.5.5 Advantages/Benefits

Benefits to this type of enhanced evaporation consist of:

- the capability of evaporating substantial amounts of water (operator data suggests up to 70 gpm), with approximately 30% evaporative loss during the months of December – February, to approximately 80% during the summer months;

- with proper management, forage and vegetation can be improved;
- towers are generally mobile, thus providing flexibility for system operations; and
- impact areas are relatively small and may avoid many surface runoff issues.

4.5.6 Disadvantages/Detriments

Detriments to the use of enhanced evaporation include:

- the lack of availability of suitable soils, as increasing clay content in the soil will decrease infiltration, which in turn increases costs;
- the amount of monitoring required of the soils beneath the evaporative facilities;
- the determination and use of the necessary soil additives to assure no degradation of ambient soil quality;
- seasonal use only requires storage or other means of water disposal during the winter; and
- the lack of knowledge of long-term impacts to soils and vegetation irrigated with spray from the atomizers.

4.5.7 Permitting and Regulatory Requirements

- WSEO Permit to construct off-channel ponds
- WDEQ Permit to discharge
- WO&GCC Permits for pit construction and pit closure may apply.

4.5.8 Cost Estimates

Tables 4.5.1 and 4.5.2 provide estimated capital costs and annual operational costs for this water management alternative. The costs assume that one tower will receive water at annual rate of 60 gpm, and will dispose of 50% of the water by evaporation; i.e., 30 gpm of water will be consumed.

Table 4.5.1
Capital Cost Estimate for Enhanced Evaporation Using Atomizers

Item	Unit	Quantity	Unit Cost	Cost	Cost
Preparation of Final Designs & Specs					$10,720
Permitting and Mitigation					$2,000
Legal Fees					n/a
Acquisition of Access & ROW					n/a
Construction Costs					
Pond/Reservoir	LS	1	$100,000	$100,000	
Tower	LS	1	$1,200	$1,200	
Trailer	LS	1	$3,000	$3,000	
Pump/Switch Gear	LS	1	$3,000	$3,000	
Construction Cost Subtotal				**$107,200**	
Engineering @ 10%				$10,720	
Subtotal #2				**$117,920**	
Contingency @ 15%				$17,688	
Construction Cost Subtotal				**$135,608**	**$135,608**
Project Cost Total					**$148,328**

Annualized capital cost: 4% @ 20 years = $148,328 x 0.07358 = $10,914/year.

Table 4.5.2
Annual Operations Cost Estimate

Item	Unit	Quantity	Unit Cost	Cost
Power	KWHRS	15,000	$0.04	$600
Maintenance/Moving	LS	1	$10,000	$10,000
Soil Mitigation	LBS	2,600	$2	$5,200
Pre-Treatment Consumables	LBS	2,500	$2.50	$6,250
Monitoring	LS	1	$5,000	$5,000
Operation Cost Subtotal				**$27,050**

Total Annual Cost: annualized capital plus operations = $(10,914 + 27,050) = $37,964/year.

Cost per 1000 gal of water = $37,694 / (30 gpm x 1440 min/day x 365 days/year)

= $2.41/1000 gallons.

4.6 Enhanced Evaporation Using Misters

4.6.1 Description

Another method of enhanced evaporation utilizes "misters". Misters are similar to equipment currently used at ski areas for snowmaking, and can be used to evaporate water into the atmosphere.

4.6.2 Purpose and Principles of Operation

Similar to tower operations, misters rely upon evaporation to dispose of water and providing sprayed water for irrigation. A number of mister options are available, either directly from the factory or customized equipment manufacturers. They can be mounted on trailers for use on land or on floats for use on lakes or reservoirs. They oftentimes have the capability to rotate automatically depending upon wind direction.

This technique is best employed either very near (just upwind) or actually on water storage containment facilities.

4.6.3 Application Criteria

While trailer-mounted misters allow substantial flexibility, float-mounted systems can avoid a number of the potential soil/water interactions common with land evaporation. The list below contains criteria for the application of both land and float systems:

- beneficial uses for livestock and wildlife have previously been exhausted;
- abundant quantities of water normally seen at startup of operations require additional disposal techniques;
- trailer or ground-mounted units will require soils with permeabilities from moderate to high;
- availability of existing ponds or lands for construction of ponds for the storage of water;
- power source readily available for pump motors; and
- soil or water amendments may be necessary to mitigate effects of dissolved constituents in the CBM water that is not evaporated and reaches the ground surface.

4.6.4 Design Criteria

- Necessary evaporative volumes range from 60-100 gpm.
- Sound water budget must be determined to maintain freeboard in the containment facility.
- Landowner-desired water quantities must be met for any water reaching soils or vegetation.
- Limitations of the equipment (efficiencies discussed in Benefits/Advantages).
- Efficiencies of this type of accelerated evaporation depend upon several factors. Firstly, as with atomizers, misters are very meteorologically dependent. Manufacturer evaporative ratings under low humidity, high temperature conditions exceed 80%, whereas efficiencies for winter and high humidity periods range from 40-50%.
- Depending upon the size of pump utilized, misters are capable of discharging from 65-100 gpm, with the key to the amount of discharge being in the amount of pressure generated by the pumping equipment. (For example, 100 psi will provide for a discharge of 66 gpm, 150 psi for 80 gpm, 200 psi for 100 gpm.) Additionally, higher pressures provide for smaller droplet sizes with resulting evaporative efficiency increases.
- Supplemental enhanced evaporation techniques at ponds may be employed through the use of black liners placed on the reservoir bottoms and piping systems that release the water onto the evaporative surface.
- In order to enhance efficiencies,
  - misters can be installed that are capable of rotating 360° and thus accommodate any wind direction,
  - nozzle angles can be adjusted to vary air residence time, and
  - a number of nozzle configurations are available to optimize performance.

4.6.5 Advantages/Benefits

Beyond the advantages described for enhanced evaporation using atomizers, a number of benefits under the right circumstances can be derived from this type of accelerated evaporation technique. They are:

- Installation of floating systems or systems placed at a reservoir's edge or within a reservoir will dramatically reduce any potential soil impacts. Decreasing or eliminating soil impacts, such as by having all water not evaporated fall back into the reservoir, will alleviate the research necessary with towers as well as possible mitigation measures. Moreover, floating systems may be more operationally feasible during winter conditions, because snow or ice falling on a frozen reservoir is not as potentially detrimental to the surface as ice and eventually runoff are to soils.

- While not minimizing soil impacts, trailer-mounted misters will allow flexibility in the location of these units.

4.6.6 Disadvantages/Detriments

Listed below are detriments and disadvantages that are possible through utilization of this water management alternative.

- Similar to other management options employing evaporative techniques, this alternative's efficiency is greatly dependent upon weather conditions and time of season. While hot, dry summertime periods allow for good efficiencies, cold or humid conditions greatly diminish this alternative's effectiveness.
- The expense associated with procurement, operation and maintenance of equipment (including power costs) substantially exceeds that required for passive evaporation. Most misting systems require at least 460/480 volt power, although some models can be operated using portable generators. Power requirements for misters are essentially the same as for atomizers.
- Mister operation on land may have detrimental effects on soils and forage quantities due to a buildup of the dissolved solids that are released from the evaporated water.

4.6.7 Permitting and Regulatory Requirements

Assuming that there is no discharge of water off of the affected land surface, the only permits required will be from the WSEO (for water storage facilities) and from the WO&GCC (if enhanced evaporation is applied at containment pits).

4.6.8 Cost Estimates

Table 4.6.1 and 4.6.2 below outline capital and operating expenses associated with accelerated evaporation utilizing misters. The costs assume that one mister will dispose of 60 gpm at an annual efficiency rate of 70%.

Table 4.6.1
Cost Estimate for Enhanced Evaporation using Misters

Item	Unit	Quantity	Unit Cost	Cost	Cost
Preparation of Final Designs & Specs					$15,120
Permitting and Mitigation					$5,000
Legal Fees					n/a
Acquisition of Access & ROW					n/a
Construction/Equipment Costs*					
Pond/Reservoir	LS	1	$100,000	$100,000	
Float-Mounted Mister	LS	1	$45,200	$45,200	
Auto-Rotate with Wind	LS	1	$6,000	$6,000	
Construction Cost Subtotal				**$151,200**	
Engineering Costs @ 10%				$15,120	
Subtotal #2				**$166,320**	
Contingency @ 15%				$24,948	
Construction Cost Total				**$191,268**	**$191,268**
Project Cost Total					**$211,388**

*Does not include cost of piping water from wells to holding pond or getting power to site

Annualized capital cost: 4% @ 20 years = $211,388 x 0.07358 = $15,554/year

Table 4.6.2
Annual Operations Cost Estimate

Item	Unit	Quantity	Unit Cost	Cost
Power	KWHRS	15,000	$0.04	$600
Maintenance/Moving	LS	1	$10,000	$10,000
Soil Mitigation	LBS	2,600	$2	$5,200
Pre-Treatment Consumables	LBS	2,500	$2.50	$6,250
Monitoring	LS	1	$5,000	$5,000
Operation Cost Subtotal				**$27,050**

Total Annual Cost: annualized capital plus operations = $(15,554 + 27,050) = $42,604/year.

Cost per 1000 gal of water = $42,604 / (60 gpm x 70% efficiency x 1440 min/day x 365 days/year)

= $1.93/1000 gallons.

4.7 Piping Water to Other Drainage Basins

4.7.1 General Description

This management alternative collects CBM-produced water and conveys it to other drainage basins besides the PRB.

4.7.2 Purpose and Principles of Operation

As opposed to attempting to dispose of or treat CBM water within the Three Horses watersheds, it is possible to collect this water, store it temporarily, and then pump it into other drainage basins. Surrounding river basins in close proximity to the Three Horses watershed, and thus conceivably available for receipt of such discharges, include the Tongue, Belle Fourche, Cheyenne and North Platte River basins.

4.7.3 Application Criteria

Water would be conveyed to a central location, at which point the water would be temporarily stored prior to being pumped up and out of the PRB. Water would again be stored in the receiving drainage basin, to be released at controlled rates to allow for suitable mixing with ambient waters.

Although such an alternative can prove to be environmentally viable, the fact that any degradation to existing water quality to out-of-basin users can create opposition to such plans. There is undoubtedly concern that problems within the PRB are being solved by users of water in other basins. Objections could likely come from both private irrigators as well as downstream states, just as Montana has raised concerns about CBM releases within the PRB. If treatment would be required, then it is reasonable to question the viability of treating water prior to discharge out of the basin. It may instead prove more cost-effective to treat waters within the PRB to levels satisfactory to downstream interests, and by so doing avoiding the sociopolitical problems associated with transbasin diversions.

No costs associated with this alternative have been developed.

4.8 Piping Water to Powder River for Direct Discharge

4.8.1 General Description

This water management alternative proposes collecting and piping all water from CBM well sites to the Powder River and directly discharging the water at that point.

4.8.2 Purpose and Principles of Operation

Pumps currently utilized for dewatering the coal seam/aquifer would be sized to pump water into a collection system constructed to collect CBM-produced water. Water would flow under pressure (vs. gravity) to the confluence of each of the Three Horses streams with the Powder River. At this point, water would be directly discharged without treatment into the Powder River.

Because of the large elevation difference between the highest pumps and confluence, there would be a need for individual pressure zones throughout each of the three valleys, with each pressure zone having water pressures in the pipelines not exceeding 150 psi. At the pressure zone boundaries, pressure-reducing valves would be installed on the pipelines. Not only would these valves maintain pressures at an acceptable, manageable level, they would also allow CBM well pumps lower in the watershed to not have as high of head requirements, thus keeping horsepower capital and operating costs lower. Blow-off (i.e., pressure-relief) valves would also be installed periodically to assure that pressures are kept to an acceptable level within each pressure zone.

The system could be constructed and operated by a private company, a consortium of CBM operators, or a governmental entity. Revenues to defray construction and operational costs could be collected from users of the system. To entice this alternative to move forward, the State of Wyoming could construct the pipeline down the main stem of the three major Three Horses channels, and perhaps the trunk pipelines down the major prongs of each of the three streams.

4.8.3 Application Criteria

This water management alternative could theoretically be applied to all lands and circumstances within the Three Horses drainage basins, as all CBM-produced water would be collected and transported to the confluence with the Powder River. The viability of this alternative, however, would remain with the acceptability of this more saline, sodic water than what has been historically delivered to the State of Montana via the Powder River.

4.8.4 Design Criteria

In order to develop reconnaissance level cost estimates, a preliminary design of such a collection system was performed for the DHCW. The design criteria used was as follows:

- Pipelines to be made of high density polyethylene (HDPE), the standard material used for handling water for CBM companies.
- Pipelines buried to a depth of six feet to prevent freezing.
- Pipelines sized to not exceed 18" in diameter, for the following reasons:
  - Pipelines of this size have been constructed in CBM areas within Wyoming, thus local contractors are knowledgeable in their construction.
  - The collection system can be enlarged as the need for conveyance expands. For instance, the one main trunk pipeline in the western part of the DHCW was originally sized to be 42". However, this alternative instead includes five 18" pipelines and one 12" pipeline, which would provide essentially the same conveyance capacity as one 42". By constructing in a phased approach (e.g., constructing just one of the 18" trunk pipelines down the main stem at this time), there would not be the need for the initial capital investment as would be necessary if one 42" pipeline was constructed.
- Any additional pump and motor costs required on CBM wells to pump into the collection system would be borne by the respective CBM operators.

The preliminary design for the DHCW produced a tabulation of components to implement the system throughout the entire DHCW. In order to develop a cost for the Three Horses watersheds, the DHCW system components were merely increased by factors directly relating to the areas of the WHCW and SHCW.

4.8.5 Advantages/Benefits

Listed below are benefits and advantages that are possible through utilization of this water management alternative.

- Eliminates water problems associated with CBM discharges onto landowners within the Three Horses basins;
- Only temporary construction disturbance to downstream landowners (vs. possible perpetual disturbance if surface water discharges are allowed);
- Eliminates need for storage facility construction;
- CBM pumps could be easily sized to accommodate system;
- Could be constructed in phases; and
- Possible hydropower generation at confluence of Three Horses streams with the Powder River.

4.8.6 Disadvantages/Detriments

Listed below are detriments and disadvantages that are possible through utilization of this water management alternative.

- Very high total capital costs required to implement system;
- Will require considerable cooperation among CBM companies to participate in regional plan;
- Fluctuation in market conditions will make CBM companies reluctant to enter into long-term contracts for water disposal;
- Large temporary disturbance to lands due to additional pipeline construction;
- No assurance that Montana will accept water of lesser quality than that which it has historically seen in the Powder River at the Moorhead, Montana gaging station;

- Does not address problems of State of Montana relating to water quality of Powder River; and
- Eliminates possible beneficial use of water within Three Horses basins.

4.8.7 Permitting and Regulatory Requirements

- State of Montana - Agreement to accept CBM-produced water of this quality in the Powder River
- WDEQ – NPDES discharge permit into Powder River
- WDEQ – Stormwater Pollution Permit
- U.S. Army Corps of Engineers – 404 permit to cross wetlands with pipelines
- Campbell and Johnson Counties – Permit to cross county roads with pipelines
- BLM – easements and rights-of-way (an environmental impact statement could be required)
- Private property owners – easements and rights-of-way

4.8.8 Cost Estimates

Table 4.8.1 provides a reconnaissance level capital cost estimate for the implementation of this water management alternative throughout the Three Horses drainage areas. Table 4.8.2 provides a similar level cost estimate to operate the collection system within the three watersheds. Costs were developed using the collection system preliminary design discussed previously for the DHCW, then assuming that quantities in the other two basins would be correspondingly modified based upon watershed areas.

A possible benefit not included as an offset to the operational costs (i.e., not included in this alternative) is the generation of hydropower at the confluence with the Powder River. At this location, the energy would have to be dissipated. Given the system parameters, it is estimated that 450 – 500 kilowatts (KW) could be generated at the Dead Horse Creek – Powder River confluence site.

Table 4.8.1
Capital Cost Estimate
Piping Water for Direct Discharge to the Powder River

Item	Unit	Qty.	Unit Cost	Cost	Cost
Prep. of Final Designs & Specs					$9,399,200
Permitting & Mitigation					$200,000
Legal Fees					$5,000
Acquisition of Access & ROW					$30,000
Cost of Construction Components					
4" HDPE Pipeline Installation	1000 FT	6,480	$ 6	$38,880,000	
6" HDPE Pipeline Installation	1000 FT	656	$ 8	$5,248,000	
8" HDPE Pipeline Installation	1000 FT	336	$ 10	$3,360,000	
12" HDPE Pipeline Installation	1000 FT	260	$ 17	$4,420,000	
16" HDPE Pipeline Installation	1000 FT	136	$ 24	$3,264,000	
18" HDPE Pipeline Installation	1000 FT	1,108	$ 30	$33,240,000	
Press. Reducing Valves	EA	372	$15,000	$5,580,000	
Construction Cost Subtotal (#1)				**$93,992,000**	
Engineering Costs @ 10%				$9,399,200	
Subtotal (#2)				**$103,391,200**	
Contingency @ 15%				$15,508,680	
Construction Cost Total				**$118,899,880**	**$118,899,880**
Project Cost Total					**$128,534,080**

Annualized capital cost: 4% @ 20 years = $128,534,080 x 0.07358 = $9,457,539/year

Table 4.8.2
Annual Operating Costs

Item	Cost
Personnel Services	$400,000
Materials and Supplies	$120,000
Contractual Expense	$120,000
Total Annual Operating Expense	**$640,000**

Total annual cost: annualized capital and operating = $(9,457,539 + 640,000)/year
= $10,097,539 / year

Cost per 1000 gal of water = $10,097,539 per year/ (114 MGD x 365 days/year)

= $0.24/1000 gal.

4.9 Water Treatment - General

Water treatment may be a viable water management alternative or a part of a more comprehensive water management alternative. Treatment may be used to achieve several different outcome objectives including:

- direct discharge;
- injection;
- infiltration; and
- irrigation.

The water treatment process to be applied depends upon the constituents of concern. In some cases, it may be metals and metalloids; in others, it may be sodium (with respect to SAR) or EC (possibly portrayed as TDS). Water treatment may be applied in several configurations, including at individual wellheads, to a pod of wells, to an entire production field, or to a complete drainage basin. Essentially, these configurations are related to the number of well discharges combined to comprise the water treatment influent scheme. There may or may not be economies of scale in dealing with water treatment, and this may require evaluation based upon individual circumstances. Taken collectively, the variables in assessing the feasibility of water treatment are considerable.

The following presents the analysis of water treatment alternatives. The preface to this analysis is the presentation of the anticipated water quality to be treated within the DHCW, WHCW and SHCW.

Tables 4.9.1, 4.9.2 and 4.9.3 present the statistical summaries of water quality shown previously for water produced by CBM development in the drainages of concern. NPDES discharge standards are also presented on the tables. Comparison of average coal bed water quality to the NPDES discharge limits shows that, with the exception of SAR and EC (for irrigation), coal bed water quality meets all applicable WDEQ discharge limitations established for the three drainages.

An alternative comparison is the "mean + 2 standard deviations", which is reflective of the upper 95% confidence interval (i.e.; 95% of all water samples are equal to or less than this value). Under the 95% confidence limit comparison criteria, SAR and EC do not meet discharge limitations as stipulated in Chapter 8 of the WDEQ Water Quality Rules and Regulations. (WDEQ 1980) Discussion of treatment of CBM water for the Three Horses drainages focuses on reducing the concentrations of these parameters to within the applicable discharge limits.

Compliance with the WDEQ anti-degradation clause in Chapter 1 of the Water Quality Rules and Regulations requires discharged water that may be utilized for downstream irrigation in the drainages may not exceed 2,000 µmhos/cm for EC. Furthermore, this discharge water must have an SAR less than 6 in DHCW and the upper parts of WHCW and less than 11 for the lower parts of the WHCW. SAR must be less than 6 in the SHCW. These two values apply at the first point of diversion for irrigation downstream of the discharge. (Hargett and Thomas 2002) These discharge limits exist only in cases where the water will reach a downstream irrigator. In the case of the DHCW, this is very near the confluence of Dead Horse Creek with the Powder River. If downstream irrigation is not affected, the EC value must not be greater than 7,500 µmhos/cm in order to satisfy stock and wildlife water quality values.

A limited sampling of runoff water quality (N=15) at this location on Dead Horse Creek shows the EC averages 3,488 µmhos/cm (mean + 2 std. dev = 7,515 µmhos/cm) and SAR averages 3.3 (mean + 2 std. dev. = 10.5). Some of this sampling was performed by EDE during the summer of 2001, whereas the remainder was performed by others on prior dates. Data from WHCW and SHCW indicate similar exceedances in runoff water quality, with mean EC in Wild Horse Creek at 2,910 µmhos/cm (mean + 2 std. dev = 6,256 µmhos/cm) and mean EC in Spotted Horse Creek at 3,211 µmhos/cm (mean + 2 std. dev = 7,300 µmhos/cm). Wild Horse Creek runoff SAR averages at 7.8 or 13.2 in the 95% confidence interval while the Spotted Horse Creek mean value was 6.2 or 13.9 in the 95%.

The data suggests that native runoff water does not meet irrigation water quality criteria, and the EC of this runoff water is actually of poorer quality than CBM discharge water.

Table 4.9.1
Dead Horse Creek CBM Water Quality[1] (Fort Union Aquifer) vs. WDEQ Discharge Standards

Parameter	CBM Water Maximum Concentration	CBM Water Mean Concentration (N=12)	Mean Plus 1 Std. Deviation (Upper 80% Confidence Level	Mean Plus 2 Std. Deviations (Upper 95% Confidence Leve	WDEQ NPDES Discharge Standard
Conductivity	2710 µmhos/cm	2307 µmhos/cm	2496 µmhos/cm	2685 µmhos/cm	7500 µmhos/cm (stock and wildlife water)
Conductivity	2710 µmhos/cm	2307 µmhos/cm	2496 µmhos/cm	2685 µmhos/cm	2000 µmhos/cm (irrigation)
pH	7.6	7.5	7.55	7.6	6.5 – 8.5
TDS	1744 mg/l	1471 mg/l	1601 mg/l	1731 mg/l	5000 mg/l
Oil & Grease	<1 mg/l	<1 mg/l	<1 mg/l	<1 mg/l	10 mg/l
Radium 226	.333 pCi/L	.238 pCi/L	.300 pCi/L	.362 pCi/L	1 pCi/L
Cl	11 mg/l	10.3 mg/l	10.8 mg/l	11.3 mg/l	46 mg/l
SO_4	<1 mg/l	<1 mg/l	<1 mg/l	<1 mg/l	3,000 mg/l
Ca	38.5 mg/l	28.7 mg/l	33.1 mg/l	37.6 mg/l	N/A
Mg	26.1 mg/l	22.1 mg/l	27.0 mg/l	25.9 mg/l	N/A
Na	669 mg/l	584.6 mg/l	626.5 mg/l	668.5 mg/l	N/A
Fe (dissolved)[2]	0.058 mg/l	0.036 mg/l	0.047 mg/l	0.057 mg/l	0.2997 mg/l
Mn(dissolved)[2]	0.162 mg/l	0.047 mg/l	0.098 mg/l	0.149 mg/l	0.629 mg/l
As total[2]	0.0015 mg/l	0.001 mg/l	0.0013 mg/l	0.0017 mg/l	0.007 mg/l
Ba total[2]	1.328 mg/l	0.834 mg/l	1.089 mg/l	1.345 mg/l	1.800 mg/l
SAR	20.7	20.0	20.5	21.1	6.0 irrigation

[1] Note: values from USGS Open File Report (00-372) and Big George Coals in DHCW.
[2] Thomas and Hargett January 2002

Table 4.9.2
Wild Horse Ck. CBM Water Quality[1] (Ft. Union Aquifer) vs. WDEQ Discharge Standards

Parameter	CBM Water Maximum Concentration	CBM Water Mean Concentration (N=14)	Mean Plus 1 Std. Deviation (Upper 80% Confidence Level)	Mean Plus 2 Std. Deviations (Upper 95% Confidence Level)	WDEQ NPDES Discharge Standard
Conductivity	2420 µmhos/cm	1777 µmhos/cm	2290 µmhos/cm	2802 µmhos/cm	7500 µmhos/cm (stock and wildlife water)
Conductivity	2420 µmhos/cm	1777 µmhos/cm	2290 µmhos/cm	2802 µmhos/cm	2000 µmhos/cm (irrigation)
pH	8.8	7.9	8.4	8.9	6.5 – 8.5
TDS	1540 mg/l	1133 mg/l	1469 mg/l	1806 mg/l	5000 mg/l
Oil & Grease	[2]	[2]	[2]	[2]	10 mg/l
Radium 226	[2]	[2]	[2]	[2]	1 pCi/L
Cl	24 mg/l	14.1 mg/l	19.5 mg/l	25 mg/l	46 mg/l
SO_4	1.3 mg/l	.7 mg/l	1.1 mg/l	1.6 mg/l	3,000 mg/l
Ca	54 mg/l	25 mg/l	39.5 mg/l	54 mg/l	N/A
Mg	29 mg/l	10.6 mg/l	19.9 mg/l	29.3 mg/l	N/A
Na	620 mg/l	440.7 mg/l	583 mg/l	726 mg/l	N/A
Fe dissolved	[2]	[2]	[2]	[2]	0.2997 mg/l
Mn dissolved	[2]	[2]	[2]	[2]	0.629 mg/l
As total	[2]	[2]	[2]	[2]	0.007 mg/l
Ba total	[2]	[2]	[2]	[2]	1.800 mg/l
SAR	29.2	20	28	36	6.0/11[3] irrigation

[1] Note: values from USGS Open File Report (00-372)
[2] No Data Available
[3] Note: SAR limit of 6 in upper areas and 11 in lower areas

Table 4.9.3
Spotted Horse Ck. CBM Water Quality[1] (Ft. Union Aquifer) vs. WDEQ Discharge Standards

Parameter[1]	CBM Water Maximum Concentration	CBM Water Mean Concentration (N=6)	Mean Plus 1 Std. Deviation (Upper 80% Confidence Level)	Mean Plus 2 Std. Deviations (Upper 95% Confidence Level)	WDEQ NPDES Discharge Standard
Conductivity	3800 μmhos/cm	2355 μmhos/cm	3269 μmhos/cm	4182 μmhos/cm	7500 μmhos/cm (stock and wildlife water)
Conductivity	3800 μmhos/cm	2355 μmhos/cm	3269 μmhos/cm	4182 μmhos/cm	2000 μmhos/cm (irrigation)
pH	8.1	7.6	7.9	8.1	6.5 – 8.5
TDS	2060 mg/l	1516 mg/l	2028 mg/l	2539 mg/l	5000 mg/l
Oil & Grease	[2]	[2]	[2]	[2]	10 mg/l
Radium 226	[2]	[2]	[2]	[2]	1 pCi/L
Cl	21 mg/l	13.6 mg/l	18.9 mg/l	24.3 mg/l	46 mg/l
SO_4	24 mg/l	5.6 mg/l	15.1 mg/l	24.7 mg/l	3,000 mg/l
Ca	27 mg/l	20.2 mg/l	27.2 mg/l	34.3 mg/l	N/A
Mg	26 mg/l	14.1 mg/l	21.6 mg/l	29.1 mg/l	N/A
Na	800 mg/l	602 mg/l	803 mg/l	1004 mg/l	N/A
Fe dissolved	[2]	[2]	[2]	[2]	0.2997 mg/l
Mn dissolved	[2]	[2]	[2]	[2]	0.629 mg/l
As total	[2]	[2]	[2]	[2]	0.007 mg/l
Ba total	[2]	[2]	[2]	[2]	1.800 mg/l
SAR	32	25.4	31.1	36.7	7.0

[1] Note: values from USGS Open File Report (00-372).
[2] No Data Available

Several treatment options exist to bring CBM water from the Three Horses drainages into compliance with applicable discharge regulations. The option selected for a particular development will depend upon a number of variables specific to the operation, the affected landowner's needs and desires, and the potential development site. These variables include, but are not limited to:

- treatment expense vs. CBM field return,
- equipment/capital available to the operator,
- discharge water uses as requested by the landowner,
- discharge water detriments to the landowners' operations,
- proximity of the development site to other CBM operators' sites,
- volume of produced water to be dealt with,
- topography within the development area,
- soil types at the point of discharge, and
- proximity of wellheads within the development field.

Details of treatment options are presented in the following subsections. Treatment options available include oxidation, reverse osmosis, ion exchange, ion sorption, reduction, and ion ratio (i.e., SAR) modification.

4.10 Water Treatment Using Reverse Osmosis

4.10.1 General Description

Reverse Osmosis (RO) can be used to treat CBM water by reducing the concentration of dissolved solids.

Osmosis is the interaction that occurs between two aqueous solutions, one of pure water (solvent) and the other having a dilute concentration of salt (solute), separated by a semi-permeable membrane. The semi-permeable membrane impedes passage of solute, but allows passage of the solvent. A difference in osmotic potential between the solvent and the solute solution will cause the pure water to flow across the semi-permeable membrane mixing with the salt water, until the salt concentrations on either side of the semi-permeable membrane are equal.

Applying pressure on the solute side of the semi-permeable membrane, the osmotic process can be reversed. This is known as Reverse Osmosis (RO). In RO, water (solvent) flows through the membrane from the salt-water solution but the components of the dissolved salt (ions) do not because they cannot pass through the membrane pores. This effectively removes the salt (ions) from the water. RO can be used to treat CBM water by removing ions (dissolved salts). The major ions present in CBM waters are typically sodium, calcium, magnesium, bicarbonate and chloride. Minor constituents such as trace metals are also reduced in concentration by RO. Water high in dissolved solids as reflected by the EC can be brought into discharge compliance, or to a quality that can be used for irrigation, drinking, stockwater, or other beneficial uses by RO treatment. RO systems can be constructed to treat less than one gpm up to several thousand gpm.

The RO process produces two streams of water at the end of treatment. One is the filtrate, or clean water. The other is the concentrate, which is the water that still contains the dissolved salts, now at a much higher concentration than the untreated water. The filtrate can be sent to discharge or use and the concentrate must be disposed of.

Figure 4.10.1 depicts the typical treatment process for RO.

4.10.2 Purpose and Principles of Operation

The purpose of RO may vary, depending upon the potential fate of the treated water. Under some circumstances, it may be possible to split the untreated CBM water flow, treat a portion of it, and mix the treated portion with untreated portions to achieve certain treatment objectives. Under this scenario, only a portion of the CBM produced water may require RO treatment, and the treatment plant size can therefore be minimized accordingly.

Operationally, the CBM produced water is collected at the wellheads and piped to a common location such as a surge tank or a lined pond. Some degree of pre-treatment of RO process water is usually necessary to remove suspended solids, remove iron/metals (if necessary), lower pH with acid or a softening agent to reduce the scaling potential, and to remove organic chemicals (activated carbon). The degree and type of pretreatment required for CBM water is dependent upon the untreated water quality. If iron and manganese are present, these may need to be oxidized and the suspended precipitate removed. Settling and/or filtration using a sand filter or cartridge filter can remove suspended solids such as oxidized iron, sediment, or algae. Micro-filtration can also potentially be used for pretreatment, depending upon the concentration of suspended solids. Other constituents that can foul the membranes, such as dissolved iron, manganese, barium, strontium, silica, and calcium carbonate, can all be controlled with anti-scalant chemicals. Such chemicals would be added at this stage of treatment.

Following pre-treatment, feed water is pumped into the RO membrane units for treatment. Treated water is routed to use or discharge, and the concentrate must be routed to disposal. In general, the quality of the concentrate is a direct reflection of the proportioning of the water, since the RO retains approximately 95% to 98% of the salts in the concentrate. A typical recovery of treated water to concentrate is 75% to 25%. This suggests an approximate concentration factor of 3 for the concentrate. Disposal of concentrate is contemplated to be via the use of full containment (zero discharge) evaporation ponds.

Following RO treatment, the RO treated water may require conditioning to achieve chemical stability. This conditioning may be accomplished by adding calcium carbonate ($CaCO_3$) to impart bicarbonate alkalinity and buffering.

4.10.3 Application Criteria

This water management alternative is most applicable under the following circumstances:

- water quality precludes direct discharge to receiving stream, (SAR > 6, EC > 2000 µmhos/cm (irrigation standard) or 7500 µmhos/cm (stock or wildlife watering);
- water quality precludes land application/irrigation, (SAR > 6, EC> 2000 µmhos/cm);
- discharge permit limitations preclude direct discharge;
- landowner need for high water quality;
- water volumes are too high for containment-and-loss ponds (> 100 gpm); and
- water quality/water volume precludes on-channel ponds.

The application of RO treatment technology must take into account the declining rate of water production inherent in depressurization/dewatering. Possibly the best use of RO to treat and discharge water is during the highest production period in the life of a typical CBM well or well field. It has been documented that the water production of a CBM well follows a declining rate with time. Typically this reflects a 50-70% annual decrease. (Gene George and Associates 2001) If modular RO units are used, it may be possible to put them in service in a well field until the water production rate declines to a point that off-channel impoundments are practical or more economical. Within one year, the typical off-channel impoundment will be as much as two to three times larger than necessary. RO unit(s) may be brought to a site and used for a period of six months to a year, or until the produced water volume has declined substantially. During this period, the water may be used for irrigation, stock water or discharged. The concentrate can be placed in the containment pond. Upon achieving the desired flow rate, the produced water is directed to the containment pond and the RO unit moved to another group of new high water production wells.

4.10.4 Design Criteria

The design criteria are the design limits or information needed for the type of treatment being examined. In the case of RO, these criteria vary widely between different vendors of equipment. The listing of required information presented below is a guide to assembling the basic information necessary for system design/specification.

Many applications may allow package plants. Package plants are pre-packaged, often skid-mounted units that essentially plug into pre- and post-processing systems, or they may be fully self-contained. Information requirements are incremental to each component.

Basic Data

Influent Q_{max}. = essentially unlimited, package plants up to 1 MGD (694 gpm)
Influent Q_{min}. = < 1 gpm
Influent Q_{ave}. = 3 well pod = 24 gpm

Surge Tank/ Flow Equalization Storage

Tank Volume = Dependent upon flow variation minimum to maximum as well cycle.
Pre-Treatment/Filtration:

Influent Total Suspended Solids
Influent Total Settleable Solids

Concentrate Pond
Cut-fill earthwork volumes
Evaporation computations
Infiltration computations
Soil suitability for embankment construction

RO Treatment Unit
Complete water quality analytical suite
Treatability testing by equipment vendor
Power requirements
Piping requirements
Removal efficiency
Permeate to concentrate ratio

4.10.5 Advantages/Benefits

The use of RO has a number of advantages:

- produces very high quality water: can reduce EC by 98%;
- allows use of produced water for anything from drinking to industrial use;
- can be purchased in package plants;
- can treat very small to very large volumes;
- can be operated seasonally if necessary;
- relatively small portable unit(s) may be configured for use at multiple sites with feed water storage; and
- flexibility with medium-sized units to be used at a site for several years, then moved to a new site.

4.10.6 Disadvantages/Detriments

Certain detriments or disadvantages to the use of RO treatment technology include the following:

- relatively high capital cost;
- relatively high operational and maintenance costs, as well as regular operator attention;
- loses efficiency with cold water;
- produces relatively large volumes of wastewater (20% or more of flow);
- requires significant power input;
- requires use of anti-scalants, anti-biological agents to maintain membranes;
- disposal of spent chemicals may require special handling; and
- depending upon specific ion-removal ratios, may actually increase SAR.

4.10.7 Permitting and Regulatory Requirements

These potential requirements are specific to the RO unit itself. Depending upon the use of the water and the fate of the concentrate, other permitting or regulatory requirements may exist.

- WSEO Water Right/Permit to Construct Concentrate Pond
- WO&GCC Permit to Construct Treatment Pits (must be lined if concentrate TDS > 10,000 mg/l)
- WDEQ Permit to Construct Water Treatment Facilities

Possible NPDES permit (if surface water discharge is planned)

- BLM – (special use permit)
- LandownerConsent/easements/other legals

4.10.8 Cost Estimates

The following cost estimates present information for three different-sized RO units. These cost presume the following three possible applications within the Three Horses drainages:

- a battery of three wells producing eight gpm per well for a maximum flow of 24 gpm;
- a production field of wells (pod) estimated at 25 wells producing an average of eight gpm per well for a maximum flow of 200 gpm; and
- a modular unit capable of 700 gpm (1 MGD) for use in a basin-wide centralized treatment system. Multiple units would be necessary but could be added as necessary depending on the rate of CBM development.

The percentage of TDS removal via the use of RO units is anticipated to be 60%.

Table 4.10.1
Reverse Osmosis Water Treatment Plant – 24 gpm (0.03 MGD)

Item	Unit	Qty.	Unit Cost	Cost	Cost
Preparation of Final Designs & Specs					$13,000
Permitting and Mitigation					$2,000
Legal Fees					$1,000
Acquisition of Access & ROW					$5,000
Cost of Construction Components					
Concentrate Disposal Pond/Reservoir	CY	30,000	$1.25	$37,500	
Surge Tank	LS	1	$3,500	$3,500	
Piping to Treatment Point	FT	1,000	$10	$10,000	
Pre-Filtration System	LS	1	$4,000	$4,000	
Chemical Pre-Treatment System	LS	1	$5,000	$5,000	
RO Treatment System	LS	1	$27,000	$27,000	
Post-Treatment System	LS	1	$5,000	$5,000	
Building	LS	1	$18,000	$18,000	
Power supply	LS	1	$10,000	$10,000	
Reclamation	LS	1	$10,000	$10,000	
Construction Cost Subtotal (#1)				**$130,000**	
Engineering Costs @ 10%				$13,000	
Subtotal (#2)				**$143,000**	
Contingency @ 15%				$21,450	
Construction Cost Total				**$164,450**	**$164,450**
Project Cost Total					**$185,450**

Annualized capital cost: 4% @ 20 years = $185,450 x 0.07358 = $13,645/year

Estimated Annual Operating Costs = $5,000/year

Cost per 1000 gal of water: annualized capital plus operating cost

= $(13,645 + 5,000) per year / (24 gpm x

1440 min/day x 365 days/year)

= $1.48/1000 gal

Table 4.10.2
Reverse Osmosis Water Treatment Plant – 200 gpm (0.28 MGD)

Item	Unit	Qty.	Unit Cost	Cost	Cost
Preparation of Final Designs & Specs					$53,000
Permitting and Mitigation					$4,000
Legal Fees					$3,000
Acquisition of Access & ROW					$20,000
Cost of Construction Components					
Concentrate Disposal Pond/Reservoir	CY	100,000	$1.25	$125,000	
Surge Tank	LS	1	$15,000	$15,000	
Piping to Treatment Point	FT	1,000	$10	$10,000	
Pre-Filtration System	LS	1	$20,000	$20,000	
Chemical Pre-Treatment System	LS	1	$8,000	$8,000	
RO Treatment System	LS	1	$250,000	$250,000	
Post-Treatment System	LS	1	$8,000	$8,000	
Building	LS	1	$50,000	$50,000	
Power Supply	LS	1	$20,000	$20,000	
Reclamation	LS	1	$20,000	$20,000	
Construction Cost Subtotal (#1)				**$526,000**	
Engineering Costs @ 10%				$52,600	
Subtotal (#2)				**$578,600**	
Contingency @ 15%				$86,790	
Construction Cost Total				**$665,390**	**$665,390**
Project Cost Total					**$745,390**

Annualized capital cost: 4% @ 20 years = $745,390 x 0.07358 = $54,845/year

Estimated Annual Operating Costs = $125,000/year

Cost per 1000 gal of water: annualized capital plus operating cost

= $(54,845 +125,000) per year / (200 gpm x 1440 min/day x 365 days/year)

= $1.71/1000 gal

Table 4.10.3
Reverse Osmosis Water Treatment Plant – 700 gpm (1.0 MGD)

Item	Unit	Qty.	Unit Cost	Cost	Cost
Preparation of Final Designs & Specs					$136,100
Permitting and Mitigation					$5,000
Legal Fees					$5,000
Acquisition of Access & ROW					$100,000
Cost of Construction Components					
Concentrate Disposal Pond/Reservoir	CY	200,000	$1.25	$250,000	
Surge Tank	LS	1	$20,000	$20,000	
Piping of Treatment Systems	FT	1,000	$10	$10,000	
Pre-Filtration System	LS	1	$28,000	$28,000	
Chemical Pre-Treatment System	LS	1	$9,000	$9,000	
RO Treatment System	LS	1	$925,000	$925,000	
Post-Treatment System	LS	1	$9,000	$9,000	
Building	LS	1	$65,000	$65,000	
Power Supply	LS	1	$25,000	$25,000	
Reclamation	LS	1	$20,000	$20,000	
Construction Cost Subtotal (#1)				**$1,361,000**	
Engineering Costs @ 10%				$136,100	
Subtotal (#2)				**$1,497,100**	
Contingency @ 15%				$224,565	
Construction Cost Total				**$1,721,665**	**$1,721,665**
Project Cost Total					**$1,967,765**

Annualized capital cost: 4% @ 20 years = $1,967,765 x 0.07358 = $144,788/year

Estimated Annual Operating Costs = $330,000/year

Cost per 1000 gal of water: annualized capital plus operating cost

= $(144,788 + 330,000) per year / (700 gpm x 1440 min/day x 365 days/year)

= $1.29/1000 gal

4.11 Water Treatment Using Ion Exchange

4.11.1 General Description

Ion exchange (IX) is a reversible chemical reaction wherein an ion (an atom or molecule that has lost or gained an electron and has thus acquired an electrical charge) from solution is exchanged for a similarly-charged ion attached to an immobile solid particle. These solid IX particles are either naturally-occurring inorganic zeolites or synthetically-produced organic resins. The synthetic organic resins are the predominant type used today because their characteristics can be tailored to specific applications and typically have a much larger exchange capacity per unit weight.

In a most general sense, a synthetic IX resin consists of a network of hydrocarbon radicals to which are attached soluble ionic functional groups (the exchangeable ion). The hydrocarbon molecules are cross-linked in a three-dimensional matrix, imparting overall insolubility and toughness to the resin. This cross-linking also increases the surface area and number of active sites on the resin.

Because ions must diffuse into and out of the resin for exchange to occur, ions larger than a given size may be excluded from reaction by proper selection of the degree of cross-linking. Within this matrix, the charge of the ionic groups attached to the framework of the resin determines to a large extent the behavior of the resin. The total number of groups per unit weight of resin determines the exchange capacity, and the group type affects both the IX equilibrium and the ion selectivity.

Cationic IX resins exchange for positively charged ions, whereas anionic IX resins exchange for negatively-charged ions. Once all of the exchangeable ions have been used, forcing the captured ions off of the exchange sites and replacing them with the original exchangeable ion regenerates the resin. The regeneration fluid may be acidic, basic or a high concentration salt solution. The regeneration fluid and post regeneration flushing produces a waste effluent that requires disposal.

Figure 4.11.1 portrays a typical process diagram for IX treatment. IX is used extensively for water and wastewater treatment, primarily for the removal of "hardness" ions: calcium and magnesium, and for removal of iron. Most people are familiar with IX in the form of a household water softener. In water softening, the calcium and magnesium are exchanged from the water to the exchange resin for sodium. The concentration of calcium and magnesium in the water is reduced, and the concentration of sodium is increased proportionately.

The situation with most CBM water is that it is desired to reduce only the sodium concentration. Alternatively, it may be desirable to reduce the concentration of dissolved constituents in total. The latter is referred to as de-ionization. This process is similar to IX.

4.11.2 Purpose and Principles of Operation

Industrial applications of IX use fixed-bed column systems. The basic component is the resin tank or column. The column supports the resin, distributes the feed water and regeneration flow through the bed, and includes piping valves and controls to operate the system. As applied to CBM water, if the water is low in suspended solids (which it should be if pumped directly from the wells), the feed water is routed directly into the IX column. Upon leaving the column, the desired constituent(s) have been removed and the water can then be discharged or used as appropriate.

After the feed solution is processed to the extent that the resin becomes exhausted and cannot accomplish further IX, the resin must be regenerated. The column is backwashed to remove suspended solids collected by the bed during the service cycle. The backwash flow fluidizes the bed and releases trapped particles. Following backwash, the resin bed is flushed with the regenerant solution.

In the case of a cation resin, acid elutes the collected ions and converts the bed to the hydrogen form (i.e.; hydrogen ions displace the captured ions from the resin). A slow water rinse then removes the residual acid. The bed is then flushed with the appropriate high-strength solution of the exchangeable ion to displace the hydrogen and prepare the resin for service. The nature of the regenerant solution is specific to the exchangeable ion used and the resin type. A final fast-water rinse is used to remove the regenerant solution and prepare the bed for service flow.

The frequency with which this regeneration cycle must be performed is dependent upon the resin IX capacity and the concentration of ions in the feed water. If the feed water solution contains very high concentrations of the ions to be removed, the regeneration must be conducted, often at the expense of chemical use and, therefore, cost. Efficient chemical use is the principal concern in maintaining cost control over the process.

The regenerant solution must be disposed of. Depending upon the nature of the regenerant solution, this may be done by pumping the solution to an impoundment for evaporation. The regenerant solution may require neutralization or other post-use treatment. Regenerant use may be possible with strong acid – strong base systems, resulting in improved chemical efficiency. Weak acid – weak base systems are typically more efficiently regenerated, and the increasing capacity is nearly linear with regenerant dose.

IX can produce very high quality water, often achieving as much as 99% retention of the target ion(s). If this degree of retention is not required, the feed water flow may be split, and treated water can then be blended with untreated water to achieve the desired result without treatment of the entire flow. The wastewater generated by IX varies directly with the frequency of regeneration. The clean water recovery by IX can vary from 95% to less than 70%, depending upon the frequency of regeneration. Water to be treated must be tested on a bench scale to determine the response to IX and to determine the regeneration frequency and chemical requirements. This can be calculated; however, bench-scale testing is strongly recommended.

4.11.3 Application Criteria

This water management alternative is most applicable under the following circumstances:

- water quality precludes direct discharge to receiving stream
  (SAR > 6; exchangeable ion concentrations of 350 mg/l as $CaCO_3$ or less);
- water quality precludes land application/irrigation,
  (SAR > 6; exchangeable ion concentrations of 350 mg/l as $CaCO_3$ or less);
- discharge permit limitations preclude direct discharge,
  (metals or metalloid concentrations above limits);
- interruption of downstream water rights preclude on-channel impoundment;
- landowner need for high quality water; and
- water volumes are too high for containment and loss ponds,
  (economic limit of IX as compared to RO is exchangeable ion concentrations of 350 mg/l as $CaCO_3$ or less depending on regenerant chemical cost variations).

The application of IX may be economically limited for use in treating most CBM water treatment due to relatively high TDS concentrations. Statistical evaluation of CBM water quality within the Three Horses drainages indicates that none of the samples meet the "rule-of-thumb" IX economic limit of 350 mg/l TDS. Data sets, however, are limited, and there may be examples in which water quality **does** meet the limits.

Applying an ion-selective resin to target sodium may improve the financial ability to achieve this economic limit. However, with mean TDS values ranging from 1,133 mg/l to 1,516 mg/l, few ion-selective resins are economically capable of handling this type of water. Given the limited data set and high variability of water quality in the drainages, some percentage of wells may meet the economic limits of IX applications, but whether or not the treated water would then meet required discharge limits would be questionable.

Utilization of IX treatment technology must take into account the declining rate of water production inherent in depressurization/dewatering. If modular IX units are used, it may be possible to put them in service in a well field until the water production rate declines to a point that off-channel impoundments are practical or more economical. Within one year following well field startup, the typical off-channel impoundment will be as much two to three times larger than necessary. IX unit(s) may be brought to a site and used for six months to a year, or until the produced water volume has declined substantially. During this period, the water may be used for irrigation, stockwater or directly discharged. The regenerant can be placed into the containment pond. Upon achieving the desired flow rate (at which time the untreated CBM-produced water would be routed directly to the containment pond), the IX unit can be moved to another group of new high-water production wells. The IX system may be left in place and continue to be used, as the effective turndown ratio of this treatment system is essentially unlimited. Though sized for large flows, the declining rate of feed water will result in longer IX column runs prior to regeneration. IX columns can be easily operated intermittently as well.

4.11.4 Design Criteria

The design criteria are the design limits or information for the type of treatment being examined. In the case of IX, these criteria vary somewhat between different vendors of equipment and different resins. The listing of required information presented here is a guide to assembling the basic information necessary for system design/specification.

Potential CBM applications may allow the use of package plants. Package plants are pre-packaged, often skid-mounted units that essentially plug into pre- and post-processing systems, or they may be fully self-contained. Information requirements are incremental to each component.

Basic Data:

Influent Q_{max}. = essentially unlimited, package plants up to 1 MGD (694 gpm)
Influent Q_{min}. = < 1 gpm
Influent Q_{ave}. = 3 well pod = 24 gpm

Surge Tank / Flow Equalization Storage:

Not absolutely required. System may be fed directly from well fields if pressures and pipeline geometry allows.
Tank Volume = Dependent upon flow variation minimum to maximum as well cycle.

Pre-Treatment/Filtration:

Iron oxidation and precipitate settling or filtration

Regenerant Disposal Pond:

Cut-fill earthwork volumes
Evaporation computations
Infiltration computations
Soil suitability for embankment construction
Possible liner requirement

IX Treatment Unit:

Complete water quality analytical suite
Treatability testing by equipment vendor/resin manufacturer/engineer
Power requirements
Piping requirements
Removal efficiency
Ion selectivity; good selectivity for sodium is questionable
Regenerant/backwash to produced water ratio

4.11.5 Advantages/Benefits

The use of IX has a number of advantages:

- produces very high quality water; (cation/anion IX can reduce EC by 99.9%);
- may be ion-selective (e.g., sodium);
- allows use of produced water for anything from drinking to industrial use;
- can be purchased in package plants;
- can treat very small to very large volumes;
- can be operated seasonally if necessary;
- relatively small portable unit(s) may be configured for use at multiple sites with feed water storage;
- flexibility with medium-sized units to be used at a site for several years, then moved to a new site;
- requires little energy/power input;
- requires little operator attention, possible lengthy unattended operation; and
- if applied properly, generates relatively small wastewater volume.

4.11.6 Disadvantages/Detriments

Detriments or disadvantages associated with the use of IX treatment technology include the following:

- relatively high capital cost;
- relatively high operations and maintenance costs;
- loses efficiency with higher TDS water;
- requires significant chemical input;
- disposal of spent chemicals may require special handling;
- ion selectivity to remove only sodium may be limited, thus deionization may be required; and
- may be subject to iron fouling and require iron pre-treatment.

4.11.7 Permitting and Regulatory Requirements

- WSEO — Permit to Construct Regenerant Pond
- WO&GCC — Permit to Construct Pits (must be lined if regenerant TDS > 10,000 mg/l)
- WDEQ — Permit to Construct Water Treatment Facilities
- WDEQ — Possible NPDES permit
- BLM — Special Use Permit
- Landowner — Consent/Easements/other legals

4.11.8 Cost Estimates

The following cost estimates present cost information for three different-sized IX units. Capital costs can vary widely, depending upon the selected cycle time of the system designed. These costs presume several possible applications within the DHCW, and further assume that the technology is applied only to water quality of 300 ppm as $CaCO_3$ or less (which is essentially the economic breakpoint as compared to reverse osmosis):

- A battery of three wells producing eight gpm per well, for a maximum flow of 24 gpm.
- A production field of wells (pod) estimated at 25 wells producing an average of 8 gpm per well for a maximum flow of 200 gpm.
- A modular unit capable of 700 gpm (1 MGD) for use in a basin-wide centralized treatment system. Multiple units would be necessary, but could be added as necessary depending on the rate of CBM development.

The percentage of TDS removal via the use of RO units is anticipated to be essentially 100%.

Table 4.11.1
Ion Exchange Water Treatment Plant – 24 gpm (0.03 MGD)

Item	Unit	Qty.	Unit Cost	Cost	Cost
Preparation of Final Designs & Specs					$9,300
Permitting and Mitigation					$2,000
Legal Fees					$1,000
Acquisition of Access & ROW					$5,000
Cost of Construction Components					
Regenerant Disposal Pond/Reservoir	CY	10,000	$1.25	$12,500	
Surge Tank	LS	1	$3,400	$3,400	
Piping to Treatment Point	FT	1,000	$10	$10,000	
Iron Removal System	LS	1	$4,000	$4,000	
Regenerant Neutralization System	LS	1	$5,000	$5,000	
IX Treatment System	LS	1	$21,000	$21,000	
Resin Replacement	LS	1	$4,000	$4,000	
Building	LS	1	$18,000	$18,000	
Power Supply	LS	1	$5,000	$5,000	
Reclamation	LS	1	$10,000	$10,000	
Construction Cost Subtotal (#1)				**$92,900**	
Engineering Costs @ 10%				$9,290	
Subtotal (#2)				**$102,190**	
Contingency @ 15%				$15,329	
Construction Cost Total				**$117,519**	**$117,519**
Project Cost Total					**$134,819**

Annualized capital cost: 4% @ 20 years = $134,819 x 0.07358 = $9,920/year

Estimated Annual Operating Costs = $20,000/year

Cost per 1000 gal of water: annualized capital plus operating cost
= $(9,920 + 20,000) per year / (24 gpm x 1440 min/day x 365 days/year)

= $2.37/1000 gal

Table 4.11.2
Ion Exchange Water Treatment Plant – 200 gpm (0.28 MGD)

Item	Unit	Quantity	Unit Cost	Cost	Cost
Preparation of Final Designs & Specs					$61,000
Permitting and Mitigation					$4,000
Legal Fees					$3,000
Acquisition of Access & ROW					$25,000
Cost of Construction Components					
Regenerant Disposal Pond/Reservoir	CY	50,000	$1.25	$62,500	
Surge Tank	LS	1	$15,000	$15,000	
Piping to Treatment Point	FT	1,000	$10	$10,000	
Iron Removal System	LS	1	$15,000	$15,000	
Regenerant Neutralization System	LS	1	$8,000	$8,000	
IX Treatment System	LS	1	$395,000	$395,000	
Resin Replacement	LS	1	$25,000	$25,000	
Building	LS	1	$50,000	$50,000	
Power supply	LS	1	$10,000	$10,000	
Reclamation	LS	1	$20,000	$20,000	
Construction Cost Subtotal (#1)				**$610,500**	
Engineering Costs @ 10%				$61,050	
Subtotal (#2)				**$671,550**	
Contingency @ 15%				$100,733	
Construction Cost Total				**$772,283**	**$772,283**
Project Cost Total					**$865,283**

Annualized capital cost: 4% @ 20 years = $865,283 x 0.07358 = $63,668/year

Estimated Annual Operating Costs = $160,000/year

Cost per 1000 gal of water: annualized capital plus operating cost

= $(63,668 + 160,000) per year / (200 gpm x 1440 min/day x 365 days/year)

= $2.13/1000 gal

Table 4.11.3
Ion Exchange Water Treatment Plant – 700 gpm (1.0 MGD)

Item	Unit	Qty.	Unit Cost	Cost	Cost
Preparation of Final Designs & Specs					$104,000
Permitting and Mitigation					$5,000
Legal Fees					$5,000
Acquisition of Access & ROW					$75,000
Cost of Construction Components					
Concentrate Disposal Pond/Reservoir	CY	100,000	$1.25	$125,000	
Surge Tank	LS	1	$20,000	$20,000	
Piping of Treatment Systems	FT	1,000	$10	$10,000	
Iron Removal System	LS	1	$20,000	$20,000	
Regenerant Neutralization System	LS	1	$12,000	$12,000	
IX Treatment System	LS	1	$700,000	$700,000	
Resin Replacement (once during 7 yrs)	LS	1	$60,000	$60,000	
Building	LS	1	$60,000	$60,000	
Power Supply	LS	1	$15,000	$15,000	
Reclamation	LS	1	$20,000	$20,000	
Construction Cost Subtotal (#1)				**$1,042,000**	
Engineering Costs @ 10%				$104,200	
Subtotal (#2)				**$1,146,200**	
Contingency @ 15%				$171,930	
Construction Cost Total				**$1,318,130**	**$1,318,130**
Project Cost Total					**$1,507,130**

Annualized capital cost: 4% @ 20 years = $1,507,130 x 0.07358 = $110,895/year

Estimated Annual Operating Costs = $570,000/year

Cost per 1000 gal of water: annualized capital plus operating cost

= $(110,895 + 570,000) per year / (700 gpm x 1440 min/day x 365 days/year)

= $1.85/1000 gal

4.12 Water Treatment Using Ion Ratio Modification

4.12.1 General Description

One of the more difficult compliance and environmental issues is related to the CBM produced water's SAR. As stated previously, the SAR is a ratio among calcium, magnesium and sodium ion concentrations. Stated simply, high concentrations of sodium relative to calcium and magnesium are undesirable.

The addition of salts of calcium and magnesium can be used to shift the ratio of these ions relative to sodium. Limestone (calcium carbonate), dolomite (magnesium carbonate), gypsum (calcium sulfate), magnesium sulfate, (epsom salt) magnesium chloride, calcium chloride or various combinations of these can be added to water to decrease SAR levels. High SAR water, when applied to certain at-risk soils, will lose soil structure through sodium de-flocculation of clays and retention of salts, and will become unsuitable for agriculture. The addition of calcium and magnesium shifts the SAR, and, theoretically, the effects of elevated sodium on the soil are minimized.

The increase in calcium and magnesium concentrations relative to sodium decreases the sodic hazard. However, the corresponding increase in TDS (or EC) will in turn increase the salinity hazard such that the total net effect is not positive for the water or the soils. It is therefore cautioned that, although the ion ratio among calcium, magnesium and sodium may be altered for the better, the specific effect of each salt should be well known and investigated before applying such treatment to water to be used for irrigation. Further discussion of chemical amendments to soils is presented in Section 4.16 - Land Application of this study.

Application of limestone or gypsum to soils or water is a commonly used agricultural amendment technique and is the foundation for a number of commercially available products designed to pre-treat irrigation water. There are several ways that this pre-treatment can be accomplished. Aside from the direct agricultural effects, from a CBM discharge compliance perspective, if the SAR is high and the EC is relatively low, it may be possible to shift the SAR by adding calcium and magnesium and remain within discharge limits for EC.

4.12.2 Purpose and Principles of Operation

There are several methods that provide for the addition of calcium and magnesium to water. These include solid and liquid feed systems. Figure 4.12.1 depicts a solid feed system utilizing a limestone/gypsum dissolution bed for ion ratio modification, and Figure 4.12.2 portrays a liquid feed system utilizing a calcium/magnesium solution injection.

Solubility values and rates of dissolution limit the amount and how these constituents may be added. In addition, the increase in EC should be minimized to avoid non-compliance with the EC standard and to minimize negative effects of total salinity aside from the sodicity caused by sodium concentrations.

One aggressive method of addition is to first acidify the water with sulfuric acid. This decreases the pH level and increases the solubility of limestone and gypsum, as well as increasing the rate of dissolution. It does not increase the equilibrium concentration of either gypsum or limestone; however, the applicable EC limits will be exceeded long before the solubility limits are achieved. The acidified water is then exposed to limestone or gypsum, or both, to dissolve these compounds and increase the calcium and magnesium concentrations. Although this procedure does work, process control is poor. Process control is gained mainly through the degree of acidification and the time of exposure to the limestone or gypsum. Attempts to apply this by lining ponds with limestone rock or gypsum have failed due to iron precipitation blinding these materials from dissolution. Iron removal may be necessary prior to implementing this type of passive treatment.

Use of more soluble salts, such as magnesium chloride, calcium chloride and magnesium sulfate, provides superior process control, as saturated solutions can be fed by chemical feed pump injection into the water. The rate of feed can be determined/calibrated based upon the increase in the conductivity. It may be possible to install a conductivity probe with a control loop to a chemical feed pump to maintain concentration proportioned feed. An alternative method is to install a flow meter and feed reagent in a flow proportioned manner.

4.12.3 Application Criteria (Utilizing Calcium Chloride, Magnesium Chloride, or Magnesium Sulfate Solution Addition For Ion Ratio Modification)

Application criteria for the use of this treatment technique are likely to be drainage specific. Dead Horse Creek only has a single irrigation water right, located near the confluence with the Powder River. Therefore, the applicable discharge limitations for SAR and EC are 6 and 2000 µmhos/cm, respectively. Water quality data from the Big George CBM well samples shows that the mean EC is 2,307 µmhos/cm, and the mean SAR is 20. To decrease the SAR to less than 6, an additional 250 mg/l of both calcium and magnesium would be required. The net effect on the EC requires laboratory determination but is somewhat irrelevant, as any increase will make the water unsuitable for irrigation and thus not a candidate for ion modification. Similarly, SHCW water quality indicates values far above the irrigation limits and any increase in calcium and magnesium to decrease the SAR would further increase the EC. The WHCW, with a mean EC of 1777 µmhos/cm, may have water more conducive to ion modification. However, with an average SAR of 25.4, it will take a significant amount of calcium and magnesium to decrease the SAR to either 11 or 6, and these amendments will likely increase EC to a concentration far above the 2000 µmhos/cm limit.

It is believed that ion modification may be an effective water treatment technique in portions of the Three Horses drainages. Even slightly lower EC and/or SAR values in the CBM-produced water would make ion modification a viable water management alternative. Variations in the produced water from the various coal seams, as well as within the areal extent of the Three Horses drainages, may demonstrate that the actual CBM water quality used herein for this analysis may be a worst- case scenario only. More acceptable CBM water quality would improve the viability of this water treatment technique.

This water management alternative is most applicable under the following circumstances:

- water quality precludes direct discharge to receiving stream, (SAR > 6, EC << 2000 µmhos/cm (irrigation criteria);
- water quality precludes land application/irrigation; (SAR > 6, EC << 2000 µmhos/cm (irrigation criteria)
- interruption of downstream water rights preclude on-channel impoundment; and
- costs or logistics preclude reverse osmosis or ion exchange.

4.12.4 Design Criteria

The information required for design of an ion ratio modification system is:

- influent Q_{max};
- influent Q_{min};
- influent Q_{ave};
- soils (types, depths, perm, etc.) for irrigation areas only;
- topography for system siting;
- pond availability and size (for iron removal or limestone/gypsum contact);
- proximity to surface stream;

- water quality analysis to include at a minimum: calcium, magnesium, sodium, carbonate; and,
- bicarbonate, sulfate, pH, EC, chloride, iron.

4.12.5 Advantages/Benefits

The use of ion ratio modification has the following advantages:

- simple system for addition of Ca and Mg;
- results in a water suitable for irrigation;
- very low capital cost compared to other treatments;
- moderate operating cost compared to other treatments;
- low energy use;
- low land disturbance;
- good process control with some systems; and
- unattended operation/infrequent maintenance.

4.12.6 Disadvantages/Detriments

Detriments or disadvantages associated with the use of IX treatment technology include the following:

- will increase the water EC;
- based upon most water quality samples analyzed to date in the Three Horses drainage basins, this method of water treatment will prove unsuitable;
- requires regular maintenance of chemical feed systems;
- may encounter future opposition due to salt loading potential issues; and
- may require more detailed examination of specific salt effects on irrigable soils downstream (i.e.; effect of magnesium sulfate or magnesium chloride).

4.12.7 Permitting and Regulatory Requirements

• WSEO	Permit to Construct Regenerant Pond
• WO&GCC	Permit to Construct Treatment Pits
• WDEQ	Permit to Construct Water Treatment Facilities
	Possible NPDES permit
• BLM	Special Use Permit
• Landowner	Consent/Easements/other legals

4.12.8 Cost Estimates

The cost of system construction and operation varies considerably, depending upon the specific approach taken. Two example systems were used to determine costs:

- Iron removal, acidification, discharge to a lime/gypsum dissolution pond or tank; and
- Direct feed of concentrated solution of magnesium chloride, calcium chloride and magnesium sulfate.

As this technology merely adjusts the balance between sodium and both calcium and magnesium, there is no TDS removal associated with this treatment alternative.

Table 4.12.1
Ion Ratio Modification Water Treatment Plant – 100 gpm (0.19 MGD)
Limestone/Gypsum Dissolution Pond

Item	Unit	Qty.	Unit Cost	Cost	Cost
Preparation of Final Designs & Specs					$4,400
Permitting and Mitigation					$1,000
Legal Fees					$1,000
Acquisition of Access & ROW					$20,000
Cost of Construction Components					
Limestone/Gypsum Dissolution Pond	CY	10,000	$1.25	$12,500	
Piping of Treatment Systems	FT	500	$10	$5,000	
Iron Removal System	LS	1	$5,000	$5,000	
Chemical Injection System	LS	1	$3,700	$3,700	
Building	LS	1	$6,000	$6,000	
Power supply	LS	1	$5,000	$5,000	
Reclamation	LS	1	$7,000	$7,000	
Construction Cost Subtotal (#1)				**$44,200**	
Engineering Costs @ 10%				$4,420	
Subtotal (#2)				**$48,620**	
Contingency @ 15%				$7,293	
Construction Cost Total				**$55,913**	**$55,913**
Project Cost Total					**$82,313**

Annualized capital cost: 4% @ 20 years = $82,313 x 0.07358 = $6,057/year

Estimated Annual Operating Costs = $5,000/year

Cost per 1000 gal of water for annualized capital cost
= $(6,057 + 5,000) per year/(100 gpm x 1440 min/day x 365 days/year)

= $0.21/1000 gal.

Table 4.12.2
Ion Ratio Modification Water Treatment Plant – 100 gpm (0.19 MGD)
Calcium, Magnesium Solution Injection

Item	Unit	Qty.	Unit Cost	Cost	Cost
Preparation of Final Designs & Specs					$3,000
Permitting and Mitigation					$2,000
Legal Fees					$1,000
Acquisition of Access & ROW					$20,000
Cost of Construction Components					
Mixing Tank	LS	1	$3,400	$3,400	
Piping to Treatment Point	FT	500	$10	$5,000	
Building	LS	1	$6,000	$6,000	
Power supply	LS	1	$5,000	$5,000	
Reclamation	LS	1	$10,000	$10,000	
Construction Cost Subtotal (#1)				**$29,400**	
Engineering Costs @ 10%				$2,940	
Subtotal (#2)				**$32,340**	
Contingency @ 15%				$4,851	
Construction Cost Total				**$37,191**	**$37,191**
Project Cost Total					**$63,191**

Note: Operational costs highly dependent upon chemical costs and raw water quality.

Annualized capital cost: 4% @ 20 years = $63,191 x 0.07358 = $4,650/year

Estimated Annual Operating Costs = $2,700/year

Cost per 1000 gal of water for annualized capital cost

= $(4,650 + 2,700) per year / (100 gpm x 1440 min/day x 365 days/year)

= $0.14/1000 gal

4.13 Piping Water to Powder River and Constructing Water Treatment Facilities

4.13.1 General Description

This water management alternative includes two previous alternatives:

- collection of water and piping water to the Powder River; and
- a water treatment alternative.

This new alternative proposes treating the water to a level such that the State of Montana would not see degradation in Powder River water quality at the gaging station at Moorhead, Montana. For purposes of analysis of this alternative, RO units are proposed to be used for water treatment.

4.13.2 Background

In August 2001, the states of Wyoming and Montana entered into a Memorandum of Cooperation (MOC) regarding water quality issues pertaining to the Powder River as a result of CBM activities. (WDEQ 2001) While specifics surrounding this MOC have not yet been formalized, the fact that the MOC was signed indicates a willingness of the two parties to cooperate on this important issue, and the potential that an agreement could be reached on the quality and quantity of CBM water that could be released into the Powder River with general acceptance by Montana.

USGS Gaging Station #6324500 on the Powder River at Moorhead, Montana (just downstream [i.e., northeast] of the Wyoming-Montana state line) has been the site of historical sampling of water quality and water quantity for the Powder River as it enters Montana. The decade of the 1980's contains the most water quality data for this station, although even this data is sporadic in portions of years 1984 through 1986.

Figures 4.13.1 and 4.13.2 portray EC and sodium levels as they relate to flow and time over this ten-year period of record that has been collected from the Powder River at the Moorhead gaging station. (Sodium in this case is used vs. SAR due to the lack of significant amounts of data for the latter.) Also shown in these figures are mean values for EC and sodium of CBM water as it is produced within the Three Horses drainages and shown previously in Tables 4.9.1, 4.9.2 and 4.9.3. These mean values are 2,146 µmhos/cm for EC and 543 mg/l for sodium.

The following deductions can be made in analyzing the data on water quality and flow at the Moorhead, Montana gaging station:

- As a general rule, the higher the flow in the river, the less concentration of EC and sodium. This assumption makes sense, given the fact that higher flows indicate more higher quality water being available from ephemeral sources such as snowmelt or rainfall to mix with and dilute the more perennial sources of water that usually have lower quality.
- The mean value of EC for CBM-produced water (2,146 µmhos/cm) is just slightly higher (2%) than the mean value of EC in the Powder River at the Moorhead gaging station (2,103 µmhos/cm) for the years of record.
- The representative value of sodium for CBM-produced water (543 mg/l) is more than twice as high (110%) as the mean value for sodium in the Powder River at Moorhead (258 mg/l) for the period of record.

Data on similar water quality constituents over the same period of time (i.e., 1980 – 1989) was also obtained from USGS Gaging Station #6317000 on the Powder River at Arvada, Wyoming. Concentrations were historically somewhat higher over the same period of time than those at Moorhead, Montana. This phenomena is likely due to the beneficial influence of Clear Creek upon the Powder River water at Moorhead, as Clear Creek discharges into the Powder River between the two stations approximately 16 miles southwest and upstream of the Wyoming-Montana state line. Water quality concentrations within Clear Creek are typically much lower (i.e., better water quality) due to this tributary's high-mountain source being much closer than that of the Powder River.

There are no municipal or industrial users of Powder River water in Montana; however, some lands are irrigated to some extent with Powder River water throughout the river's 150-mile trek through Montana to the confluence with the Yellowstone River (located approximately 30 miles downstream of Miles City). There are only two significant tributaries to the Powder River in Montana: the Little Powder River and Mizpah Creek. Neither contributes significant additional flow.

An informal survey conducted by the Montana Department of Environmental Quality indicated that most irrigators do not use scientific means for determining when Powder River water can be applied to their lands. (Horpestad 2002) However, those that do use such means use the value of 1500 µmhos/cm as a "rule of thumb maximum value" in determining when water quality is acceptable for irrigation from the Powder River. Additionally, most irrigators utilize Powder River – when water quality is acceptable – from March through September. Due to the fact that Montana irrigators can only occasionally now utilize Powder River for their purposes, it may be a safe assumption that further degradation of Powder River water due to CBM discharges may not be tolerated by the State of Montana.

The Powder River in the vicinity of the Three Horses drainage area provides little if any irrigation to Wyoming irrigators. The Wyoming State Board of Control (BOC) does not administer water rights on the Powder River in this vicinity because:

- water rights on the Powder River below Reno Junction are all junior in priority, thus their regulation would have no effect on upstream senior users, and
- due to the poor water quality of the Powder River usually prevalent in this reach, the time of actual use for irrigation is dictated by the quality of the stream (which changes during the year depending upon the stream flow) rather than actual need. (Loguidice 2002)

As discussed above, preliminary information indicated that the mean EC value of a typical CBM water from the Three Horses watershed is approximately the same as the mean EC value for the Powder River during the 1980's at Moorhead. On the other hand, the sodium value of a typical CBM water from the Three Horses drainage is 110% higher than the mean of the measured sodium values for the Powder River at Moorhead during the same period. In order to match the Moorhead gaging station's historical concentration for sodium, it is proposed with this alternative that some of the water arriving at the confluence with the Powder River be treated using one of the water treatment techniques discussed in the previous section; in this case, RO units. The treated water would then be blended with untreated water to provide for the required concentration to meet historical values seen at the Moorhead station.

Using the mean CBM and Moorhead data values for sodium cited above, and assuming that RO units are capable of a 60% removal efficiency as described in Section 4.10 – Water Treatment Using Reverse Osmosis, it is calculated that approximately 88% of the water collected at the confluence of the three basins would have to be treated with RO units capable of removing 60% of the sodium in the water. (In so doing, TDS values would be reduced by 60% as well.) The remaining 12% of the water would be untreated and mixed with the treated water to provide water quality similar to what has been historically seen at the USGS Moorhead station for sodium, and less than values seen for EC.

Based upon the removal efficiencies and blending percentages described above, and assuming the previous numbers for well spacing (80 acres), discharge (8 gpm per well) and number of wells (two per site), a total discharge of 114 MGD would be conveyed via the collection systems described in Section 4.8 to the confluence with the Powder River. At the confluences, a series of RO units with a total capacity of 100 MGD would be required.

This scenario represents a very conservative assumption regarding buildout of CBM development within the Three Horses drainage areas. The likelihood of all wells within the three basins coming on line simultaneously is remote; however, should natural gas prices increase, there may be development seen at levels considerably higher than those now witnessed.

4.13.3 Purpose and Principles of Operation

This alternative couples the collection system discussed in the previous alternative with treatment of the water prior to discharge. Untreated water would arrive at the water treatment plant housing the RO units, at which point the pressure in the main would have to be reduced to atmospheric pressure. Water would then be stored in a basin, out of which water would be pumped through the RO units and undergo treatment to remove 60% of the dissolved solids, including sodium. Treated water from the RO units would be mixed with untreated water from the basin and then discharged into the Powder River. Produced concentrate (brine) would be dewatered by applying to drying beds or hauled away for further processing. Dried material would be hauled to a landfill for ultimate disposal.

It may be possible to utilize the pressure head available from the collection system to substitute for some of the pumping required into and as part of the RO units.

Depending upon the outcome of negotiations with the State of Montana, it may be possible to utilize the water treatment plant during the irrigation season only. During the non-irrigation season, water would be allowed to be released directly without treatment to the Powder River.

4.13.4 Application Criteria

As with the first water management alternative, this water management alternative could theoretically be applied to all lands and circumstances within the entire Three Horses drainage areas, as all CBM-produced water would be collected and transported to the confluence with the Powder River.

It is anticipated that water produced from the RO units would meet drinking water standards. The possibility of providing this treated water to consumers in lieu of mixing it with untreated water and discharging it to the Powder River was briefly explored. However, due to the few number of residences within the Three Horses drainage areas and the considerable distance to potential water markets such as Sheridan, Buffalo or Gillette, this concept was not considered further.

As sodium is such a small ion, there is the possibility that calcium and magnesium may be removed in greater proportions than sodium, thus actually increasing SAR levels. However, overall EC would decrease significantly due to the reduced concentration of dissolved solids in the filtrate.

4.13.5 Design Criteria

- All design criteria listed in the water management alternative that proposed a basinwide collection system would similarly apply.
- The number of RO units – and thus the flow rate of water treated - would be initially small, and would increase as the need for further units dictates. As such, the need for a large initial capital investment could be minimized and funded as the need for treatment increased;

4.13.6 Advantages/Benefits

- Elimination of discharges onto lands within the watersheds
- Elimination of holding ponds and reservoirs for CBM waters (although ponds or reservoirs may be required for brine storage or iron/manganese removal prior to RO treatment)
- Only temporary construction disturbance to downstream landowners (vs. perpetual disturbance if surface water discharges are allowed)
- Possibility of hydropower at confluence of Dead Horse Creek and Powder River
- Water treatment could be curtailed or eliminated during periods of high flows in the Powder River, which often occur in the spring or after significant precipitation events.

4.13.7 Disadvantages/Detriments

- High annual capital and operating cost
- Disposal of RO concentrate stream uncertain at this time
- No assurance that Montana will accept water with similar historical quality but with higher quantity than that which it has historically seen in the Powder River at Moorhead
- Temporary disturbance to lands due to additional pipeline construction

4.13.8 Permitting and Regulatory Requirements

- State of Montana - Agreement to accept CBM-produced water of this quality in the Powder River
- WDEQ – NPDES discharge permit into Powder River
- WDEQ – Stormwater Pollution Permit
- WDEQ – Permit to construct a water treatment facility
- U.S. Army Corps of Engineers – 404 permit to cross wetlands with pipelines
- Campbell and Johnson Counties – Permit to cross county roads with pipelines
- BLM – easements and rights-of-way (an environmental impact statement could be required)
- Private property owners – easements and rights-of-way

4.13.9 Cost Estimates

Table 4.13.1 provides a reconnaissance level capital cost estimate for the implementation of this water management alternative. It includes the collection system capital cost estimate identified in the previous cost alternative.

Table 4.13.2 provides a similar level cost estimate to operate both the collection system and the treatment facility. As with the first alternative, the opportunity may exist to develop hydropower to offset the power costs associated with operating an RO facility, in lieu of dissipating the water's energy prior to storing the water in the initial preliminary storage basin.

Table 4.13.1
Capital Cost Estimate
Piping Water to the Powder River with Water Treatment

Item	Unit	Qty.	Unit Cost	Cost	Cost
Prep. of Final Designs & Specs					$26,463,408
Permitting & Mitigation					$250,000
Legal Fees					$50,000
Acquisition of Access & ROW					$200,000
Cost of Construction Components					
Const. Cost Subtotal - Collection System	LS	1	$ 128,534,080	$128,534,080	
100 MGD RO WTP ($1.361 M x 100)	LS	1	$136,100,000	$136,100,000	
Construction Cost Subtotal (#1)				**$264,634,080**	
Engineering Costs @ 10%				$26,463,408	
Subtotal (#2)				**$291,097,488**	
Contingency @ 15%				$43,664,623	
Construction Cost Total				**$334,762,111**	**$334,762,111**
Project Cost Total					**$361,725,519**

Annualized capital cost: 4% @ 20 years = $361,725,519 x 0.07358 = $26,615,725/year

Table 4.13.2
Annual Operating Costs

Item	Cost
Collection System (from previous alternative)	$640,000
Treatment System ($330,000/MGD x 100 MGD)	$28,000,000
Total Annual Operating Expense	**$28,640,000**

Total annual cost: annualized capital and operating = $(26,615,725 + 28,640,000) = $55,255,725

Cost per 1000 gal of water = $55,255,725 per year/ (114 MGD x 365 days/year)

= $1.33/1000 gal.

4.14 Lake DeSmet Storage Releases

4.14.1 General Description

This water management alternative utilizes water available from Lake DeSmet to mix with CBM-produced water in order to provide water in the Powder River at such a concentration of EC and sodium that the State of Montana would not see a degradation in Powder River water quality at the gaging station at Moorhead, Montana.

4.14.2 Background

The previous alternative utilized treatment of a portion of the CBM-produced water to mix with untreated water to provide water to Montana that would have no degradation from previous water quality. Under this alternative, in lieu of treatment, water would be released from the Lake DeSmet outlet works in northern Johnson County which would then flow down Clear Creek. Being of a higher quality water than the CBM-produced water, Lake DeSmet releases would mix with CBM-produced water to provide water of a quality in the Powder River that has been historically observed at the Moorhead gaging station.

Under this alternative, a collection system may or not be required to convey water produced from within the Three Horses drainage basins to the confluence with the Powder River, at which point the water would be directly discharged into the Powder River. Water within the Powder River between the point of discharge and Clear Creek would be degraded for certain times of the year. However, as discussed in Section 4.8 (Piping Water for Direct Discharge to Powder River), the use of the Powder River as an irrigation source in Wyoming below Sussex is not regulated and is assumed to be minimal at the present time due to ambient poor water quality.

4.14.3 Purpose and Principles of Operation

Based upon the limited data available, stored water within Lake DeSmet appears to be of higher quality than CBM-produced water. Four sets of water quality data taken by the WG&FD in the 1980's and 1990's showed the TDS for Lake DeSmet to have a mean value of 565 mg/l, with a low of 510 mg/l and high of 700 mg/l. (WG&FD 2002) A 1990 study of Lake DeSmet as a potential water supply for the City of Sheridan showed it having a TDS level of 590 mg/l. (HKM 1990) Using an approximate conversion factor of EC = TDS/0.65, water within Lake DeSmet can be assumed to have an EC value of approximately 880 µmhos/cm.

The four data sets taken by the WG&FD for Lake DeSmet also provided information on sodium, ranging from a high of 32 mg/l to a high of 41 mg/l, with a mean value of 38 mg/l.

The Lake DeSmet water storage facilities and much of the stored water within Lake DeSmet was sold to a joint powers board consisting of representatives of Johnson, Campbell and Sheridan Counties by Texaco in 2000. In discussions with representatives of that joint powers board (Yates, 2002), the amount of water that could potentially be available for alternative uses such as mixing with CBM-produced water was determined to be 20,000 acre-feet (6.5 billions gallons).

Representatives from the BOC were contacted regarding the amount of conveyance loss that might occur and thus would be assessed if water was to be released from Lake DeSmet for delivery to the confluence of Clear Creek and the Powder River. These representatives stated that a 25% conveyance loss is now assessed for the delivery of Lake DeSmet water to the Pratt & Ferris diversion located just north of the Town of Clearmont. An estimate on the percentage of conveyance loss that would be assessed on Lake DeSmet water for delivery at the Clear Creek-Powder River confluence is 50%. (Loguidice 2002) Based upon the above-stated water availability and conveyance loss factor, it is assumed that up to 10,000 acre-feet per year could potentially be available for mixing in the Powder River at the Clear Creek confluence.

As discussed previously, the 10-year average for EC of water at the USGS Moorhead gaging station was placed at 2100 µmhos/cm, and the 10-year average for sodium was 258 mg/l. Utilizing a total flow of 114 MGD (349 acre-feet per day) of CBM-produced water from the Three Horses basins (based upon full development @ 80 acre spacing, 8 gpm/well, and two wells/site) and the need to have water released from Lake DeSmet "dilute" CBM water with a higher sodium level to levels typically seen at Moorhead, 10,000 acre-feet of Lake DeSmet water at the Clear Creek confluence could mix with the CBM-produced water to provide for a sodium value of 258 mg/l for a period of approximately 22 days annually.

Longer periods of release could be achieved if only one or two of the Three Horses watersheds utilized this technique. For example, if only the DHCW water was addressed with this water management alternative, Lake DeSmet water could provide for efficient mixing for a period of approximately 88 days/year.

4.14.4 Application Criteria

This water management alternative, although limited, could theoretically be applied to all lands and circumstances within the Three Horses basins, as all CBM-produced water would be collected and transported to the confluence with the Powder River. However, due to the limited availability of Lake DeSmet to mix with CBM-produced water, alternative mixing sources or other means of treating or handling water would be required for those periods when Lake DeSmet water is not available.

Assuming that landowners' concerns were addressed within the Three Horses drainage basins, there may not be the need to construct a collection system within the basins to convey water to the respective confluences of the Powder River. Instead, water could be directly discharged into streams and channels, with the mixing water from Lake DeSmet addressing Montana's concerns.

4.14.5 Design Criteria

All design criteria listed in the water management alternative described in Section 4.8 (Piping Water for Direct Discharge to Powder River) would similarly apply with this management alternative. Other than the collection system, actual facilities construction would be minimal. Instead, agreements would have to be met with the Lake DeSmet joint powers board regarding timing and duration of releases from the reservoir.

4.14.6 Permitting and Regulatory Requirements

- State of Montana - Agreement to accept CBM-produced water of this quality in the Powder River during the non-irrigation season and during those periods when mixing water is not available.
- WDEQ - NPDES discharge permit into Powder River.
- Lk. DeSmet JPB - Agreement to sell and release Lake DeSmet water, and the rate charged for the water.
- WBOC - Agreement on the amount of water ultimately conveyed to the confluence of Clear Creek and the Powder River.
- Private property owners -Easements, permission to cross downstream lands with discharged water.

4.14.7 Advantages/Benefits

- Provides relatively simple means of improving water quality of Powder River into Montana.
- Instream flow available during certain periods in Clear Creek, possibly improving fisheries and aesthetics.

4.14.8 Disadvantages/Detriments

- Very limited supply only.
- No assurance that Montana will accept water with similar historical quality but with higher quantity than that which it has historically seen in the Powder River at Moorhead.
- Lake DeSmet recreational users may oppose annual drawdowns for this purpose.
- May require collection system of CBM water within Three Horses drainage areas, or acquiescence of landowners within the drainage areas to allow flows through their property.

4.14.9 Cost Estimates

Itemized below is a reconnaissance level annual cost estimate for the purchase of Lake DeSmet water to be used for mixing with CBM water discharged from the Three Horses basins. It does **not** include the collection system capital cost estimate identified in previous water management alternatives, as it is unlikely that a collection system would be installed for the limited time that Lake DeSmet releases are available.

Purchase of Lake DeSmet Water – 20,000 A-F @ $100/A-F / 0.50 conveyance loss

= $200/A-F available at confluence of Clear Creek and Powder River

Cost per 1000 gal of water available at confluence = $200/A-F
= $0.61/1000 gal*

* requires alternate source of water during periods when Lake DeSmet water not available

4.15 Dust Abatement

4.15.1 General Description

This alternative proposes utilizing CBM-produced water on county or other improved roads as a means of disposal.

4.15.2 Purpose and Principles of Operation

Dust generated by the CBM activity has been a source of concern, particularly for operations close to residential developments. Traditionally, concentrated magnesium chloride (25-50% concentrate) has been used to flocculate dust on gravel roads. The magnesium salt binds individual soil particles into groups of particles that are resistant to displacement, thus consolidating the road base to reduce dust. Generally, the roadbed is bladed, magnesium chloride is applied by tanker truck, and then the road is again bladed to mix the magnesium chloride into the road and to compact the road base.

4.15.3 Application Criteria

The use of CBM discharge waters for dust abatement must be given careful consideration before being implemented as a management practice. Dust abatement, like other management options such as land application, will be seasonal; i.e., the application of water to the roads will likely not be utilized until mid-March and will likely cease around mid-November. As such, this water management alternative could be used for an estimated nine months (245 days) per year. While the CBM water has elevated salinity, the concentrations are not sufficient to prevent freezing of the water. Since the process is seasonal, options for off-season storage must be considered as part of the overall cost of dust abatement.

The quality of the CBM water must also be considered prior to implementing this approach. As described above, magnesium chloride is a concentrated salt and, as such, is very effective in flocculating road dust. The CBM water is of varying quality with very little chloride and very high bicarbonate concentrations. The dominant cation is sodium as opposed to magnesium or calcium.

The next section on land application discusses the interactions of high salinity and high sodium waters, and their combined effect on soils. The soils of the Three Horses drainage areas are dominated by medium-to-fine textured soils, and clays present in these soils are swelling-type clays. Most roads, particularly the operations access roads, are constructed of these soil materials, and they may or may not have gravel or crushed rock placed on top of the road. Just as high salinity in water tends to counter the soil's ability to swell in the presence of sodium, high sodium concentrations will similarly counter the salinity effect on dust flocculation.

When sodium concentrations exceed the salinity flocculation threshold over time, clays in the roadbed may swell and hold significant quantities of water. If this happens, roads could become "greasy"; i.e., similar to bentonitic roads that become wet. While the threshold level is difficult to predict, in general, as the salinity concentration increases in relation to sodium, the ability to flocculate dust will also increase. Table 4.15.1 summarizes the water classes that are likely to be unsuitable for dust suppression.

Table 4.15.1
Waters Unsuitable for Dust Suppression

Class	SAR	EC (umhos/cm)
C1S2	10 -18	0 - 250
C1S3	18 - 26	0 - 250
C1S4	>26	0 - 250
C2S2	10 - 18	250 - 750
C2S3	18 - 26	250 - 750
C2S4	>26	250 - 750
C3S4	>26	750-2250
C4S4	>26	>2250

Based upon Table 4.15.1 and representative mean values for CBM water within the Three Horses drainage areas of 2,146 umhos/cm for EC and 22 for SAR, it appears that opportunities exist within the three basins to utilize CBM water for dust suppression purposes. However, before water is applied for such purposes, more specific information on the water quality of that water which is proposed for use should be well understood before proceeding.

4.15.4 <u>Design Criteria</u>

Assuming that the CBM water is in fact suitable for use as dust suppression, the volume of water that can be disposed of in this manner compared to other scenarios can be calculated. Following is a calculation of one scenario for disposing of CBM water through dust abatement.

Typical application rates over roads for dust suppression approximates one-half inch of applied water.

Application Depth: 0.05 inches x 1 ft. per 12 inches = 0.042 ft.

Road Surface Area:
25 ft. top width x 5280 feet per mile = 132,000 square feet surface area.
20 ft. top width x 5280 feet per mile = 105,600 square feet surface area.
15 ft. top width x 5280 feet per mile = 79,200 square feet surface area.

Applied Water Per Mile:
25 ft. top width = 132,000 s.f. x 0.042 ft. = 5544 c.f. x 7.48 gal. per c.f. = 41,470 gal. per mile
20 ft. top width = 105,600 s.f. x 0.042 ft. = 4519 c.f. x 7.48 gal. per c.f. = 33,802 gal. per mile
15 ft. top width = 79,200 s.f. X 0.042 ft. = 3326 c.f. x 7.48 gal. per c.f. = 24,878 gal. per mile

Assumptions:
1) Trucks have 4000 gallon capacity;
2) Trucks are loaded at 200 gpm rate (20 minutes to load);
3) Round trip time to unload is 20 minutes; and,
4) Roads are watered for 10 hours per day. (combined fill and water time is 40 minutes)

Then:

10 hours per day x 60 minutes per hour = 600 minutes
600 min./day divided by 40 min. per load = 15 loads per day
15 loads/day x 4000 gallons per load = 60,000 gallons per day disposed water.

24 hour equalized flow rate = 60,000 gal./day x 24 hours/day x 60 min./hour

= 42 gpm.

Assuming that each CBM well discharges 8 gpm, one water truck could dispose of the water on roads from 5.25 wells for the time of year that application could be feasible. Using the DHCW as an example, and using a figure of 80 acre/spacing/CBM well and a drainage area for the DHCW of 154 square miles, a total of 235 trucks would be needed to utilize all of the produced water on the roads within the DHCW. [Note: For this one truck scenario for a 10-hour day, a storage pond of at least 35,000 gallon storage capacity is needed to handle off-hour storage at 42 gpm. Also, since the operation is seasonal, storage for 120 days at 42 gpm is approximately 72,000,000 gallons (less evaporation and leakage losses.)]

Miles Watered for Dust Abatement Daily:

25 ft. top width = 60,000 gal./day divided by 41,470 gal./mile = 1.5 miles per day
20 ft. top width = 60,000 gal./day divided by 33,802 gal./mile = 1.8 miles per day
15 ft. top width = 60,000 gal./day divided by 24,878 gal./mile = 2.4 miles per day

Obviously, the assessment of the feasibility of using CBM water for dust suppression will be determined by water quality, the gallons of water requiring disposal daily, and the cost of disposal using this method as compared to other methods. Each operation will have different needs and water quality, and the assessment must be made on operation specific inputs.

4.15.5 Advantages/Benefits

- Low initial capital cost
- Beneficial use of water
- Can aid in mitigating CBM impacts by controlling dust

4.15.6 Disadvantages/Detriments

- Limited time throughout the year that this alternative can be implemented (245 days/year)
- Some question as to how effective dust abatement can be with continued application of CBM water
- Possibility of making roads "greasy"
- Extensive number of trucks required to dispose of all of the water
- May not be enough public roads to which the water could be applied

4.15.7 Permitting and Regulatory Requirements

- Campbell, Johnson Counties - Permit to use CBM water for dust abatement on county roads
- BLM - Permit to use CBM water for dust abatement on roads located on BLM lands
- Private property owners - Permission to use CBM water for dust abatement on improved roads that are not necessarily public roads

4.15.8 Cost Estimates

Using the assumptions outlined in Section 4.1.5.4, the cost of disposal of CBM water using dust abatement can be calculated on a cost-per-1000-gallon basis for comparison to other methods.

Assumptions:

1) Water disposal rates and methods are those as outlined above;
2) The cost of off-hour water storage, off-season water storage, and water supply piping to a load-out facility are not included in these costs.
3) Costs are based on disposal of 60,000 gallons per day for 245 days per year.

Labor: 1 Manday @ 10 hours/day x 245 days/year x $10/hour x 1.4 benefits = $34,300

Tanker Truck : $60,000 at 7 years depreciation = $8570

Taxes/Insurance/License/etc.: = $ 250

Truck Maintenance: = $2000

Fuel: 245 days x 40 gallons per day x $1.15/gallon = $11,270

Pump and Standpipe: $14,500 at 7 years depreciation = $2,070

Pump Maintenance: = $400

Estimated Total Annual Cost = $58,860

Cost per 1000 Gallons:

60,000 gallons per day x 245 days = 14,700,000 gallons (equalized at 42 gpm over 24 hours)

$58,860 / 14,700,000 gallons

= $4.00/1000 gal

4.16 Land Application

4.16.1 General Description

This alternative proposes applying CBM-produced water to lands within the Three Horses drainages for the purposes of disposing of water, rangeland improvement through irrigation, or crop production.

4.16.2 Purpose and Principles of Operation

Land application may be a viable alternative for the disposal of CBM discharge water, however, land application can only be considered as a potential "beneficial use" when adequate evaluation of the land application operation occurs. That is, numerous factors must be considered before land application is undertaken. Those factors will include evaluation of site-specific soil, vegetation, topographic, water quality, and water and soil management procedures. In addition, other factors, such as seasonal climatic limitations, area available for land application, and economics will also need to be included in the planning for successful land application. This section will describe the factors and conditions that must be determined to assess both the potential risk and the potential benefit for disposal of CBM water using land application. This discussion will ultimately be geared towards providing the operator with a step-by-step procedure for evaluating land application as a viable option for their discharge water. It is very important to note that best management practices for land application will be an evolving process as new research, data, and processes emerge.

4.16.3 Application Criteria

4.16.3.1 Required Soil Characteristics

4.16.3.1.1 General

Soil characteristics important to land application evaluations include soil particle size and texture, organic matter content, structure and bulk density, clay mineralogy, infiltration rate, hydraulic conductivity, saturation percentage and depth to bedrock. In addition, chemical parameters, including EC, calcium carbonate content (lime), SAR, cation exchange capacity (CEC), exchangeable sodium percentage (ESP), and pH, must be known before a land application plan or risk assessment can be made. Sections 2.6.1, 2.6.2 and 2.6.3 describe the general baseline soil conditions for the DHCW, WCHW and SHCW, respectively, as they are currently defined.

The majority of the soil map units are comprised of soil associations or complexes. Soil associations or complexes will consist of groupings of two or more soil types that are taxonomically distinct and impossible to separate at the scale of mapping. Successful land application planning and management requires that soils be mapped to a single taxonomic unit on a site-specific basis by a qualified individual using a scale of detail that is appropriate for the site. As with "best management" of agronomic operations, successful land application management must be geared to the most restrictive soil type for the specific site. Obviously, if the most restrictive soil types are minor in composition, operational management will likely be geared towards the next most restrictive unit mapped.

4.16.3.1.2 Soil Particle Size, Mineralogy and Permeability

Since the goal of any land application process is to dispose of excess CBM waters, soil particle size is extremely critical when determining the feasibility of land application. Soil particle size and mineralogy govern numerous other soil factors including soil structure, bulk density, infiltration rate, hydraulic conductivity, and saturation percentage. Soil particle size (USDA system) includes coarse fragments (> 2mm), sand (2 to 0.05mm), silt (0.05 to 0.002mm), and clay (<0.002mm). The surface area of the soil particles influences the ability of the soil to retain adsorbed water, nutrients, and ions. In general, the smaller the average particle size the greater the total surface area per unit quantity of soil. Sections 2.1.5.4, 2.2.5.4 and 2.3.5.4 describe the range of soil particle sizes and soil textural families present in each of the Three Horses drainages. Of particular interest for land application assessment is the effect of soil particle size on water relationships in soil.

Soil permeability is the ability of the soil to transmit both water and air. Vegetative productivity is significantly impacted when the ability of soil to transmit water and air is reduced, either due to a change in soil physical characteristics or soil chemical characteristics that affect soil physical properties. Soils with higher clay concentrations have a greater effect on changes in permeability than do soils with low clay contents. Sections 2.1.5.6, 2.2.5.6 and 2.3.5.6 describe general baseline soil permeability conditions for each drainage, respectively.

In addition to their small particle size and large surface areas, clay mineralogy in the drainage basins is dominated by montmorillonite (smectitie) clays. Montmorillonite clays have layered morphologies and swell or disperse when they become wet resulting in higher soil moisture storage, slower infiltration and hydraulic conductivities, and increased soil moisture capillary rise capabilities. In addition, soil chemistry related to sodium concentrations, salt concentrations and, to a lesser extent, calcium carbonate content, also affect soil permeability. Obviously, the interaction of these factors will significantly affect land application management decisions.

4.16.3.1.3 Cation Exchange Capacity, SAR/ESP, and EC

Cation exchange is a phenomenon based upon the negative charge of clay and, to a lesser extent, organic particles in soils. Cations present in the soil, including calcium, magnesium, sodium, potassium and numerous others, can be adsorbed onto the clay exchange complex. Cation exchange is the ability of a soil to replace adsorbed cations by cations from the surrounding soil solution, and this process is referred to as the cation exchange capacity (CEC). Clay mineralogy significantly affects the CEC. Expanding clays generally have significantly higher CEC levels because cations can be adsorbed onto the interlayers of the clay particles. CEC is a preferential process; i.e., certain cations can be more easily adsorbed onto the exchange sites or held tighter on the exchange sites, making cation exchange more difficult.

The presence of significant concentrations of sodium or salts in the soil profile, or the addition of land application waters that may add appreciable concentrations of sodium or salts, will affect both the feasibility and management of potential land application operations. Sodium is easily adsorbed onto the soil exchange complex and can readily exchange with calcium and magnesium. Sodium, in the absence of significant salts in the soil solution, adsorbs on both the clay particle outer layers and in the clay inter-layers, and causes the clay particles to swell or permanently disperse and translocate into soil pore spaces. The sodium is tightly held on the exchange sites, and the swelling or dispersion results in significant reductions in soil infiltration and hydraulic conductivity rates. Swelling may be a reversible process through cation exchange or flocculation; however, dispersion and particle migration are not generally reversible. These processes have a significant effect on the ability to reclaim sodic soils or to mitigate the effects of high sodium waters on soils.

The sodicity of a soil may be evaluated in terms of the exchangeable sodium percentage (ESP); i.e., the percentage of the CEC occupied by sodium. Because exchangeable sodium directly affects the swelling and/or dispersion of soil clay particles, it is of primary significance when evaluating the effect of sodium on soils.

The calculation of ESP is based on the following equation:

$$ESP = (Na_X / CEC) \times 100,$$

where Na_X = exchangeable sodium in meq /100 gm.

Sodium is also evaluated in soils using the SAR, which, as discussed previously, is a ratio of soluble sodium to soluble calcium and magnesium. SAR theory assumes that the soluble cations in the soil solution are in equilibrium with adsorbed cations and thus can be empirically related to exchangeable sodium. As stated previously, SAR is calculated as follows:

$$SAR = Na^+_S / (Ca^{++}_S + Mg^{++}_S)^{-2} /2,$$

where Na^+_S, Ca^{++}_S, and Mg^{++}_S = soluble sodium, calcium, and magnesium (all in meq/l), respectively.

Historically, literature has suggested that an SAR of 12 in soils is approximately equal to an ESP of 15, again assuming that the soluble cations are in equilibrium with the adsorbed cations. Soils receiving CBM waters with appreciable concentrations of sodium and salts will not likely have soluble and adsorbed cations in equilibrium. In addition, for sandy and coarse-textured soils, the sodium present in the soils is largely soluble, thus SAR can significantly over-estimate the true sodic hazard. In these instances, ESP is a better indicator of the sodicity hazard in soils. Arguments against the use of ESP include the higher cost of analysis and the reliability of the ESP analyses, largely related to the determination of CEC. However, improvements in the analysis of CEC provide a more reliable method for CEC for arid and calcareous soils. (Polemio and Rhodes 1977, 1982)

The above discussion assumes that salts in the soil profile are limited. The presence of salts in the soil, or the addition of appreciable concentrations of salts through land application, can significantly alter the effects of sodium on the exchange complex. In addition, salts may be toxic to vegetation. In general, the swelling of clays tends to increase with increasing exchangeable sodium and decreasing electrolyte (salt) concentrations. At low electrolyte concentrations and low-to-moderate sodium concentrations, clays can become mobile (disperse) and can result in the plugging of conducting pores. When clays disperse, the plugging of pores may be permanent. At higher sodium concentrations, swelling of the clay particles occurs. The introduction of salts to the soil system will cause the swollen clay particles to shrink, opening soil pores.

Several researchers have looked at critical ESP levels in soils, using various electrolyte concentrations, that result in reductions in soil hydraulic conductivity. (Frenkel, et al, 1978; McNeal and Coleman, 1966; Rowell, et al, 1969; Bower and Rhodes, 1972; Velasco-Melino, 1970; Shainberg and Caiserman, 1971; Felhendler, et al, 1974; Rhodes and Ingvalson, 1969) Table 4.16.1 provides a summary of that research as it relates to varying clay concentrations.

Only data from montmorillonitic clays has been presented. It is important to use this information solely as a guide, and that site-specific conditions and water quality can result in significant differences with these research results.

Table 4.16.1
Critical ESP in Soils Where Reductions in Hydraulic Conductivity Occurs

	Critical ESP at Selected Electrolyte Concentrations*		
% Clay	**1000 µmhos/cm**	**2000 µmhos/cm**	**4000 µmhos/cm**
10	27%	33%	44%
20	22%	27%	37%
30	17%	23%	31%
40	12%	18%	25%
50	7%	13%	18%
60	3%	7%	13%

*Based on 25% reduction in Hydraulic Conductivity

While the above table does not necessarily reflect conditions to be encountered during land application of CBM waters, it does adequately reflect the important effect of high salt waters on the swelling of clays. This type of information is essential in assessing the potential risks associated with land application. (Refer to upcoming Section 4.16.3.1.9 for risk assessment discussions.)

4.16.3.1.4 Calcium, Magnesium, and Carbonates

Most arid or semi-arid soils contain calcium carbonate or lime, often concentrated at the top of the soil "C" horizon, where downward soil moisture leaching is countered by upward soil moisture capillary rise.

However, it is likely that some calcium carbonate is present throughout the soil profile. The presence of lime in soil is important for the assessment of land application procedures. Calcium at the surface of soils tends to be precipitated as carbonates in the presence of high bicarbonate waters. When the calcium precipitates as carbonates, soil crusting and pore plugging occurs, resulting in significant reductions in the water infiltration rate into the soil. In addition, the reaction of calcium with high bicarbonate waters can also cause precipitation of calcium with depth, and can also result in plugging of pore spaces. This phenomenon is generally not as pronounced when land application occurs with high chloride or high sulfate waters.

When calcium and magnesium are precipitated as carbonates, the relative concentrations of calcium and magnesium are reduced, and the relative proportion of sodium is increased. The net result can be increases in relative ESP. Calcium carbonate also has implications for the amendment of sodium and salt-affected soils. (Refer to upcoming Section 4.16.3.1.8 – Vegetation Characteristics for further discussion on this issue.)

4.16.3.1.5 Depth to Bedrock

The depth to bedrock in soils has significance in land application processes as it relates to the rooting depth of vegetation, total water storage capacity, and to the ability to leach salts from the root zone. Of most importance to land application is the ability to leach salts to depths below the root zone. As described previously in this section, and again in upcoming Section 4.16.3.1.8 – Vegetation Characteristics, salinity can have toxic effects on vegetation through its effect on the soil osmotic potential. Methods of calculating the salt leaching requirement are described in upcoming Section 4.1.16.3.1.9 – Land Application Management Options.

4.16.3.1.6 Topography and Erosion

The topography and erosion potential of land application sites must be considered when evaluating process efficiencies and feasibilities. Erosion potential for the Three Horses drainage basins has been previously described in Sections 2.1.9, 2.2.9 and 2.3.9 – Erosion Potential. Erosion is controlled by soil texture, soil chemistry, vegetative cover, slope steepness, and slope length. Obviously, long steep slopes devoid of vegetation are not likely to be adequate land application sites.

The erosion potential of soils that receive CBM land application can change significantly from that of natural soils, due to changes in the soil chemistry at the surface of the soil. Increases in sodium concentrations at the soil surface can result in dispersion of soil clay and significant increases in the potential of the soils to erode. Sodium, or the precipitation of calcium as carbonates at the soil surface, can also result in reduction of infiltration rates, creating increases in the potential for land application water to runoff. The clay content and soil texture will then become important criteria to assess when determining the potential for increased soil erosion due to the presence of sodium.

As discussed previously, the presence of salts in the water can help to alleviate the concern for clay swelling or dispersion to occur. However, as noted, excess salts may be toxic to vegetation, and as vegetation dies, the potential for erosion increases.

4.16.3.1.7 Water Quality Relationships

The relationship of the possible effects of CBM water on soils and vegetation, when land applied, has been discussed throughout this section. One of the earlier attempts to classify water for irrigation (land application) suitability was accomplished by the U.S. Salinity Laboratory in Riverside, California in 1954. They produced Handbook No. 60, Diagnosis and Improvement of Saline and Alkali Soils (reprinted in 1969). Handbook No. 60, Figure 25 was a diagram for the classification of irrigation water using both water sodium (SAR) concentrations and water salinity (EC) levels. (U.S. Salinity Lab. 1954)

Handbook No. 60 Figure 25, presented here as Figure 4.16.1, has been considered for years to be the leading reference for irrigation water suitability. The two-dimensional water classification system classified irrigation suitability from low-hazard waters (Class C1S1; SAR <10, EC <250 µmhos/cm) to very high-hazard waters (Class C4S4; SAR > 26, EC > 2250 µmhos/cm).

Figure 25 from Handbook No. 60 does not adequately address the effect of electrolyte (salt) concentration on the potential for swelling or dispersion of clays. In addition, Figure 25 does not consider the potential for dispersion and translocation of soil clays at relatively low sodium and salt concentrations. As a result, efforts have been made to revise the interpretations of irrigation (land application) water quality.

Table 4.16.2 summarizes a compilation of the current understanding of water quality suitability. The table summarizes the work of previously referenced researchers and discussions with Dr. Jim Bauder at Montana State University. (Bauder 2002) The table data is still two-dimensional, but must assume that the suitability is related to medium and fine-textured soils, and also assumes that sufficient leaching of salts below the root zone occurs. Final discussion on potential risks associated with CBM water quality is outlined in Section 4.16.3.1.9 – Land Application Risk Assessments and is based on a multi-dimensional approach.

Table 4.16.2
Land Application Water Quality Suitability*

Class	SAR*	EC* µmhos/cm	Relative Risk
C4S1	0-10	>2250	Very Low
C4S2	10-18	>2250	Very Low
C2S1	0-10	250 – 750	Very Low/Low
C3S1	0-10	750-2250	Very Low/Low
C3S2	10-18	750-2250	Low/Mod. Low
C4S3	18-26	>2250	Low/Mod. Low
C4S4	>26	>2250	Moderate
C2S2	10-18	250-750	Moderate
C1S1	0-10	0-250	Moderate
C3S3	18-26	750-2250	Mod. High
C2S3	18-26	250-750	Mod. High
C3S4	>26	750-2250	High
C2S4	>26	250-750	High
C1S2	10-18	0-250	High
C1S3	18-26	0-250	Very High
C1S4	26+	0-250	Very High

* Based on modification of Handbook No. 60 and above-cited literature.

4.16.3.1.8 Vegetation Characteristics

The potential adverse effects of applying CBM discharge water to vegetation is two-fold:

- the effect salinity has on the ability of a plant to adsorb water, and
- the potential for certain ions to be toxic to vegetation.

Soil water flows from areas of high water potential to areas of low water potential. Soil water potential is comprised of four components that are additive:

- the gravitational potential,

- matric (soil moisture retention) potential,
- pressure (atmospheric pressure effects on saturated and unsaturated soils) potential, and
- solute or osmotic potential.

The solute potential is related to the concentration of salts in the soil solution. The solute potential does not influence liquid water flow but does have an effect on water uptake by plants, as well as on evaporation. Solute potential affects the ability of water to flow across semi-permeable membranes - in this case, plant roots. As the solute concentration increases, the ability of plant roots to adsorb water decreases, causing drought-like stress in the plants, even when soil moisture content is adequate. In addition, when evaporation occurs at the soil surface, salts are left behind at the surface. These processes are called the osmotic effect.

The second potential adverse effect of salinity in the soil on plant growth is the potential for an increase in concentration of ions that have a characteristic toxic effect on plant metabolism. These effects are in addition to the osmotic effect, and they are referred to as the specific-ion effect. Plants vary in their ability to tolerate soil salinity. Because of the semi-arid environment that formed the soils in the three drainage basins, most of the native vegetation is at least moderately salt tolerant. Research on the salt tolerance of agronomic crops is extensive, but research on the salt tolerance of native plant species is much more limited. In addition, vegetation salt tolerance for high bicarbonate waters has also not been extensively studied. Figure 4.16.2 provides a summary of the relative salt tolerance of several forage species as compiled by James et al. (James et al, 1982)

Several current research projects at the University of Wyoming (UW) and Montana State University (MSU) are designed to help answer some of the vegetation issues related to the application of CBM waters onto native soils and vegetation. The majority of the ongoing vegetation research has centered on riparian or drainage bottom vegetation species related to direct discharge of CBM water in the drainages.

UW research conducted a vegetation buffer strip demonstration project in Burger Draw (Sue Draw), located primarily in Johnson County, during 2000. Plants used in this demonstration were Nebraska sedge *(Carex nebraskensis* Dewey), water sedge (*Carex aquatilis* Wahl), and Baltic rush (*Juncus balticus* Wild). These plant species were chosen based on field observations and known salt tolerance. The purpose of the study was to "evaluate how the three selected plant species would perform:

- when subjected to perennial flow of CBM product water,
- when subjected to grazing,
- in closure of inter-space between individual plants, and
- in different channel conditions" (Patz et al. 2002).

Results of the study indicated that vegetation establishment by the three selected plant species was very poor. "The low survival and establishment of this demonstration can be attributed to species selection, planting design, and natural encroachment of native vegetation" (Patz, et al. 2002). While these factors are likely valid, the research project did not consider the quality or quantity of the CBM water as a potential contributing factor in the low survival rates. The fact that natural encroachment and natural vegetative selection were rapidly occurring may also be significant information for future predictions on vegetative changes within drainages.

Vegetation research at MSU includes the establishment of 72 four-foot columns that will examine the growth and salt tolerance of two varieties of salt bush and a perennial hay barley. The columns have established water tables comprised of CBM water from the Powder River and Tongue River CBM operations in Montana and Wyoming. Solute chemistry and vegetation salt tolerance are also being monitored. Preliminary results of these studies will be available later this year.

In addition, MSU has established vegetation growth boxes using native soils from the basins and several native hydrophytic plants. The vegetation is watered with CBM waters, and the vegetation response is measured. Certain hydrophytic plants release carbonic acid from their roots. Carbonic acid is capable of dissolving carbonates in the soils, releasing calcium for exchange with sodium. In addition, the solute chemistry draining from the boxes is analyzed. Preliminary results of these studies will be available later this year.

Another MSU study is also looking at the salt tolerance of numerous plant species. The study is focusing currently on alfalfa varieties but will be expanded to up 150 separate plant species, including varieties of hay barley that appear to be very salt tolerant. Preliminary results of these studies will be available later this year.

Finally, MSU is studying the potential for wetland soils and plants to provide passive treatment of CBM waters. Several large ponds have been excavated and filled with native soils from the CBM drainages. The ponds have been covered with greenhouses and seeded with hydrophytic plants. The water to the wetlands is provided by CBM wells. Preliminary results of these studies will be available later this year.

While Figure 4.16.2 provides some information on relative salt tolerances, future ongoing research will provide much more specific data on vegetation, water quantity and salt tolerances.

4.16.3.1.9 Land Application Risk Assessments

The following procedures outline a step-by-step process for assessing the potential risk of land application of CBM discharge waters. The previous discussions were intended to provide a general understanding of the importance of looking at all of the soil, vegetation, and water quality issues that will affect the successful management of land application operations. It is very important to understand that risk assessment cannot be based on one-dimensional or two-dimensional theories, such as Figure 25 from Handbook No. 60, but must be as multi-dimensional as practical.

This process is applicable to all three drainages and assesses risk based upon native soil and vegetation conditions and does not assume that special management practices will be utilized to decrease potential risk. **The risk assessment does assume that sufficient leaching of salts below the root zone occurs.** (For more information on determining leaching requirements, see Section 4.1.16.5.5 – Salinity Leaching Requirement). Once the potential risk is evaluated, information in Section 4.1.16.5.5 can be utilized to determine if the risk can be decreased or mitigated.

4.16.3.1.9.1 Risk Assessment Procedures

Tables 4.16.3, 4.16.4, and 4.16.5 have been generated to assist in the risk assessment process. Again, note that this process produces a general risk assessment based upon the detail of information currently available.

Table 4.16.3 provides a complete listing of the Three Horses drainage basin soil series that occur on Figures 2.1.6 (DHCW), 2.2.2 (WHCW – South), 2.2.3 (WHCW – North) and 2.3.2 (SHCW).

Table 4.16.3
Map Unit Numbers and Textural Families Occurring in the Three Horses Drainage Areas

Map Unit Number	Textural Family	Map Unit Number	Textural Family	Map Unit Number	Textural Family	Map Unit Number	Textural Family
100	fine loamy	164	very fine	227	fine	296	coarse loamy
101	fine loamy	165	coarse loamy	228	fine	298	coarse loamy
102	fine silty	166	fine loamy	229	fine	299	coarse loamy
103	coarse loamy	167	fine loamy	233	fine loamy	304	fine loamy
104	coarse loamy	168	fine loamy	234	fine loamy	305	fine loamy
105	coarse loamy	169	coarse loamy	235	fine loamy	306	fine
106	coarse loamy	170	sandy	236	coarse loamy	307	fine loamy
107	coarse loamy	171	sandy	237	coarse loamy	309	fine silty
108	coarse loamy	172	coarse loamy	238	coarse loamy	310	coarse loamy
109	fine loamy	174	coarse loamy	239	fine loamy	312	fine loamy
110	coarse loamy	176	fine	241	fine loamy	313	fine loamy
111	fine loamy	177	fine loamy	242	fine loamy	314	coarse loamy
112	fine loamy	180	sandy	244	coarse loamy	315	coarse loamy
113	fine loamy	181	fine	245	sandy	316	fine
114	coarse loamy	182	coarse loamy	246	fine	317	fine
115	coarse loamy	183	fine	247	fine silty	320	fine loamy
116	fine loamy	184	fine	248	fine loamy	324	fine silty
117	fine loamy	185	coarse loamy	249	fine loamy	327	coarse loamy
121	fine loamy	186	coarse loamy	250	fine loamy	329	coarse loamy
122	fine loamy	187	fine loamy	251	na	330	coarse loamy
123	fine loamy	188	sandy	252	fine loamy	331	coarse loamy
124	fine loamy	189	fine silty	253	fine	332	coarse loamy
126	fine loamy	190	fine loamy	255	fine	337	fine silty
127	fine loamy	192	fine loamy	256	coarse loamy	350	fine loamy
128	fine loamy	196	coarse loamy	257	coarse loamy	351	fine
129	coarse loamy	198	fine loamy	260	coarse loamy	352	fine loamy
130	coarse loamy	199	fine	261	fine	353	fine loamy
131	coarse loamy	200	fine	262	fine	354	fine
132	coarse loamy	201	fine loamy	263	coarse loamy	355	fine loamy
133	coarse loamy	202	fine loamy	264	coarse loamy	356	fine loamy
134	coarse loamy	203	coarse loamy	265	coarse loamy	357	fine loamy
135	coarse loamy	204	fine	266	fine loamy	358	fine loamy
136	coarse loamy	205	fine	267	fine loamy	359	coarse loamy
138	fine	206	fine	268	fine loamy	360	fine
139	sandy	207	fine	273	fine	361	fine
140	coarse loamy	208	fine	274	fine loamy	362	fine
142	fine silty	209	fine	275	fine silty	363	fine loamy
143	fine	210	coarse loamy	277	fine loamy	364	fine loamy
144	coarse loamy	211	fine loamy	278	coarse loamy	365	fine
145	fine loamy	212	coarse loamy	279	fine loamy	366	fine
146	coarse loamy	213	coarse loamy	280	fine	367	fine
147	coarse loamy	214	fine loamy	281	fine loamy	368	fine
148	coarse loamy	215	fine loamy	282	coarse loamy	369	fine loamy
149	coarse loamy	216	fine loamy	283	fine loamy	370	fine loamy
153	fine loamy	217	fine loamy	286	fine	371	fine loamy
154	fine loamy	218	coarse loamy	287	fine	372	fine loamy
155	fine	220	sandy	288	coarse loamy	373	coarse loamy
157	coarse loamy	221	coarse loamy	289	coarse loamy	374	fine loamy
158	coarse loamy	223	fine loamy	292	coarse loamy		
159	coarse loamy	224	fine loamy	293	coarse loamy		
160	coarse loamy	225	fine loamy	294	coarse loamy		

The soil series are individual soil taxonomic units that occur in the Order 3 soil survey of the basin. For risk assessment purposes, the detail of the Order 3 soil survey must be considered as representing the general soils of the area and is not intended to represent detailed site-specific soils information. Table 4.16.3 also provides a soil textural family for each map unit. An example of this process is provided for clarification following the procedure description.

1) For general risk assessment, locate the potential land application area(s) on Figure 2.1.6, 2.2.2, 2.2.3 or 2.3.2 and record the map unit symbol. For a site-specific detailed assessment, the

operator should utilize a qualified soil scientist to map the soils at the proposed land application site to individual soil taxonomic units. This mapping should be conducted at a scale sufficient to delineate individual soil units to the series level. Note that risk assessments should be made for each individual soil type, and each type should be considered a management unit.

2) From Table 4.16.3, find the soil map unit name.
3) Using the soil map unit number, note the corresponding soil textural family for that map unit.
4) The textural family information will be used in Table 4.16.4 to determine the preliminary risk.

Table 4.16.4 compares water quality data to soil quality data in order to determine a preliminary risk for land application given a particular water quality. This table was compiled using the soil quality information presented in Section 4.16.3.1- General Soil Characteristics and the suitability classes and scientific information discussed in Section 4.16.3.1.7 - Water Quality Relationships.

5) Evaluate available CBM water quality data proposed for land application and determine the SAR and EC of that water. For initial assessments, use the most restrictive water quality to assess preliminary risk.
6) Using the SAR and EC data, determine the suitability "Class" of the water in Table 4.16.4, e.g., C1S1, C3S2, etc.
7) Using the "Textural Family" data derived in 3) above, find the corresponding risk level for the given water quality class and textural family. This is the **preliminary risk** for the site.

Once the preliminary risk is assessed, the risk assessment should be modified by the factors described in Table 4.16.5. Included in this table are the following factors:

- soil chemistry (SAR risk and EC risk),
- slope, erosion risk,
- depth to bedrock, and
- permeability risk.

These factors have the ability to change the overall risk evaluation; i.e., a factor such as excessive slope could change a preliminary risk assessment rated low or very low to a risk assessment rated high or very high. None of the factors listed in Table 4.16.5 will improve a risk rating.

8) Using the soil map unit information generated in Numbers 1 through 4 above, find the map unit number in Table 4.16.5.
9) Examine the risk factor rating for each of the factors in the table and record the most restrictive factor and rating.
10) Use the risk rating to modify the preliminary risk rating, as necessary. For example, if the preliminary rating is moderate, a moderate rating from Table 4.16.5 would not change the overall risk of the site for land application. A rating above moderate, such as high or very high, will change the overall risk assessment to the factor listed in the table. This is an estimate of your **Final Risk Assessment**.

Table 4.16.4
Water Quality Class vs. Soil Quality For Preliminary Risk Assessment

Water Quality			Soil Textural Families					
CLASS	SAR*	EC* umhos	Sandy	Coarse Loamy	Coarse Silty	Fine Loamy	Fine Silty	Fine
C4S1	0-10	>2250	VL	VL	VL	VL	VL	L
C3S1	0-10	750-2250	VL	VL	VL	VL	VL	L
C2S1	0-10	250-750	VL	VL	VL	L	L	L
C4S2	10-18	>2250	VL	VL	VL	L	L	M
C3S2	10-18	750-2250	VL	L	L	L	L	M
C4S3	18-26	>2250	VL	L	L	M	M	MH
C4S4	26-32+	>2250	VL	L	L	M	M	MH
C2S2	10-18	250-750	VL	M	M	M	M	MH
C1S1	0-10	0-250	VL	M	M	M	M	MH
C3S3	18-26	750-2250	VL	M	M	M	M	H
C2S3	18-26	250-750	VL	M	M	MH	MH	H
C3S4	26-32+	750-2250	L	M	M	MH	MH	H
C2S4	26-32+	250-750	L	M	M	MH	MH	H
C1S2	10-18	0-250	L	M	M	H	H	VH
C1S3	18-26	0-250	L	H	H	H	H	VH
C1S4	26-32+	0-250	L	H	H	VH	VH	VH

* Based on modified Handbook No.60 Figure 25 and Published lieterature sources as referenced above.

SOIL TEXTURES

Texture	%Clay	%Silt	%Sand
sand	0-10	0-15	85-100
silt	0-12	80-100	0-20
loamy sand	0-15	0-30	70-90
sandy loam	0-20	0-50	44-80
silt loam	0-27	50-80	0-50
loam	7-27	28-50	33-52
sandy clay loam	20-35	0-28	45-80
silty clay loam	27-40	40-73	0-20
clay loam	27-40	15-52	20-45
sandy clay	35-55	0-20	45-65
silty clay	40-60	40-60	0-20
clay	40-100	0-40	0-45

SOIL TEXTURAL FAMILY DEFINITIONS

Sandy - sand or loamy sand, <15% clay
Coarse loamy - >15% fine sand or coarser and <18% clay
Fine loamy - >15% fine sand or coarser and 18 to 34% clay
Coarse silty - <15% fine sand or coarser and <18% clay
Fine silty - <15% fine sand or coarser and 18 to 34% clay
Fine - 35 to 59% clay
Very Fine - 60% or more clay

Table 4.16.5
Land Application Risk Assessment Modifiers

Map Unit #	Slope Risk	Erosion Risk	SAR Risk	EC Risk	Bedrock/ Watertable	Perm. Risk	Map Unit #	Slope Risk	Erosion Risk	SAR Risk	EC Risk	Bedrock/ Watertable	Perm. Risk
100	L	L-M	M	H-VH	L	H	**159**	L	L	L	L	L	L
101	L	M	H-VH	H-VH	L	H	**160**	H	M	L	L	L	L
102	L	M	H-VH	H-VH	L	H	**164**	H-VH	M	L	L	H-VH	H
103	L	M	L	L	L	M	**165**	H-VH	L-M	L	L	L	L
104	M	H	L	L	L	M	**166**	M	M	L	L	L	L
105	L-M	M	L	L	L	M	**167**	L-M	M	L	L	L	H
106	H	M	L	L	M	M	**168**	L-M	L-M	L	L	M	H
107	L-M	M	L	L	M	M	**169**	L-M	L	L	L	L	L
108	H	M	L	L	L	M	**170**	H-VH	L-M	L	L	M	L
109	M	L-M	L	L	L	H	**171**	M	M	L	L	M	L
110	M	L-M	L	L	L	H	**172**	M	M	VH	VH	L	VH
111	M	L-M	L	L	L	H	**174**	L-H	M	L	L	M	M
112	H	M	L	L	L	H	**176**	M-H	L	L	L	M	M
113	M	M	L	L	L	H	**177**	L-M	L	L	L	L	M
114	H-VH	M	L	L	H	M	**180**	H	M	L	L	M	M
115	M-H	M	L	L	M	H	**181**	L-M	M	L	L	L	H
116	M	L	L	L	L	M	**182**	L-M	L-M	L	L	L	H
117	H	M	L	L	L	M	**183**	L-M	M	L	L	M	H
121	M	M	L	L	M	M	**184**	H	H	L	L	M	H
122	H	M	L	L	M	M	**185**	L-M	L-M	L	L	L	M
123	H	M	L	L	M	M	**186**	H	M	L	L	L	M
124	H	M	L	L	M	M	**187**	L-M	L-M	L	L	L	M
125	H	M	L	L	M	M	**188**	H-VH	L-M	L	L	M	VL
126	L-M	L-M	L	L	M	M	**189**	L-M	M	L	L	L	M
127	H	M	L	L	M	M	**190**	M-H	M	L	L	M	H
128	H	H	L	L	M	M	**192**	L-M	L-M	L	L	L	H
129	L-M	L	L	L	L	L	**196**	L-M	L	L	L	L	M
130	H	M	L	L	L	M	**198**	L-M	L-M	L	L	L	M
131	M	L	L	L	L	M	**199**	L-M	M	L	L	M	H
132	L-M	L	L	L	L	M	**200**	H	VH	L	L	M	H
133	H	M	L	L	L	M	**201**	H	H	L	L	M-H	H
134	L-M	L	L	L	M	M	**202**	H	H	L	L	M-H	H
135	H	M	L	L	M	M	**203**	L-M	M	L	L	L	M
136	M	L	L	L	L	M	**204**	H-VH	H	L	L	H	H
137	M	M	L	L	L	M	**205**	H	VH	L	L	H	VH
138	M	M	L	L	L	M	**206**	H-VH	VH	L	L	H	H
139	M-H	L	L	L	L	L	**207**	L-VH	VH	L	L	H	H
140	H-VH	L-M	L	L	L	L	**208**	M	M	L	L	M	H
142	L	H	VH	VH	L	H	**209**	H	H	L	L	M	H
143	VL	L	M	M	L	VH	**210**	H-VH	VH	L	L	M	M
144	L-M	L	L	L	L	M	**211**	VH	VH	L	L	H	M
145	L-M	L	L	L	L	M	**212**	L-M	L	L	L	L	L
146	L-M	L	L	L	L	M	**213**	H-VH	L-M	L	L	M-H	L
147	H	M	L	L	L	M	**214**	M	L-M	L	L	M	M
148	L-M	L	L	L	L	M	**215**	H-VH	H	L	L	M	M
149	H	M	L	L	L	M	**216**	H-VH	H	L	L	M	M
153	L	H	L	L	L	M	**217**	M-VH	VH	L	L	M	M
154	L-M	M	L	L	L	H	**218**	M-H	M	L	L	M	M
155	L	M	M	H	L	H	**220**	M-VH	L-M	L	L	M-H	L
157	L	L	L	L	M	M	**221**	H-VH	L-M	L	L	M	L
158	H	M	L	L	M	M	**223**	M	M	L	L	M	M

Table 4.16.5 (cont'd)
Land Application Risk Assessment Modifiers

Map Unit #	Slope Risk	Erosion Risk	SAR Risk	EC Risk	Bedrock/ Watertable	Perm. Risk
224	M	L-M	L	L	M	M
225	M-VH	H	L	L	M-H	M
227	L-M	L-M	L	L	L	H
228	L-M	L-M	L	L	M	H
229	H	VH	L	L	M	H
233	VH	VH	L	L	M	M
234	VH	VH	L	L	M	M
235	L-M	L	L	L	L	L
236	L-M	L	L	L	M	L
237	L-M	L	L	L	L	L
238	M	L	L	L	M	L
239	H-VH	M	L	L	M	M
241	H-VH	M	L	L	H	L
242	L-VH	M	L	L	H	L
244	L-VH	M	L	L	M	M
245	VH	L	L	L	VH	L
246	L-M	M	L	L	L	H
247	L-M	M	L	L	L	H
248	L-M	L	L	L	L	M
249	H	L	L	L	L	M
250	H	L	L	L	M	M
251	N/A	N/A	N/A	N/A	N/A	N/A
252	L-M	M	H-VH	H-VH	L	H
253	L-M	M	H-VH	H-VH	L	H
255	L-M	H	L	L	L	H
256	L-M	M	L	L	L	H
257	L	L	L	M-H	L	H
260	L-M	M	L	L	M	M
261	L-M	H	L	L	L	H
262	VL	VL	M	VH	L	H
263	L-M	L	L	L	L	M
264	M-H	M	L	L	M	M
265	L-H	L	L	L	L	M
266	VL-M	M	L	L	L	H
267	VL-M	M	L	L	L	H
268	M-H	M	L	L	M	H
273	L-M	M	L	L	L	H
274	H-VH	H	L	L	M	H
275	L-M	M	L	L	L	M
277	L-H	M	L	L	M	H
278	H-VH	H	L	L	H	M
279	M-H	M	L	L	L	H
280	M	M	L	L	M	H
281	H-VH	H	L	L	M	M
282	M	M	L	L	M	M
283	H-VH	H	L	L	M	M
286	L-M	M	L	L	L	H
287	M	M	L	L	L	H
288	H-VH	H	L	L	M	L
289	M-VH	H	L	L	M	L
293	M-VH	H	L	L	H	M
294	H-VH	H-VH	L	L	H	M
296	VL-M	M	L	L	L	M
298	VL-M	L	L	L	L	L-M
299	VL-M	L	L	L	L	L
304	VL-L	L	L	L	L	L-M
305	M-H	H	L	L	H	H
306	M-H	H	L	L	H	M
307	VH	VH	L	L	H	M
309	VL-M	M	L	L	L	H
310	VH	VH	L	L	H	M
312	VH	VH	L	L	H	M
313	H-VH	H-VH	L	L	H	M
314	M-H	M	L	L	M	L
315	VL-L	L	L	L	L	L
316	VL-M	M	H	H	L	VH
317	M-H	H	L	L	H	M
320	H-VH	VH	L	L	H	M
324	VL-L	L	L	L	L	H
327	M-VH	M	L	L	H	M
329	H-VH	H	L	L	VH	M
330	H-VH	M	L	L	VH	M
331	M-VH	M	L	L	VH	M
332	H-VH	M	L	L	VH	M
337	VL-M	M	L	L	M	M
350	L-M	L	L	L	L	H
351	L-M	L	L	L	L	H
352	L-M	L	L	L	L	L-M
353	L-M	L	L	L	L	M-H
354	H-VH	H	L	L	H	M
355	VH	VH	L	L	H	M
356	VH	VH	L	L	H	M
357	VH	VH	L	L	VH	M-H
358	H-VH	VH	L	L	H	M
359	H	M-H	L	L	H	L-M
360	H-VH	VH	L	L	H	H
361	M	L	L	L	L	H
362	H	L	L	L	L	H
363	H	M	L	L	L	M
364	M	L	L	L	L	M
365	M-H	M	L	L	H	H
366	M-H	M	L	L	H	H
367	L-H	M	L	L	H	H
368	L	L	L	L	M	H
369	VH	VH	L	L	H	M
370	VH	VH	L	L	VH	M
371	VH	VH	L	L	H	M
372	M-H	VH	L	L	VH	M
373	H-VH	VH	L	L	VH	M
374	L	L	L	L	H	M

4.16.3.1.9.2 Risk Assessment Example

1) Using the DHCW as an example, from Figure 2.1.6, the map unit that corresponds with the proposed land application area is Map Unit 147.

2) and 3) From Table 4.16.3, the textural family for this map unit number is fine-loamy.

4) This information will now be used in Table 4.16.4 for further assessment.

5) Given information provided by the CBM operator, available water quality data for CBM wells planned for land application have an average SAR = 17, and an EC = 3200 μmhos/cm.

6) From Table 4.16.4, the suitability "class" for this water quality is C4S2.

7) From Table 4.16.4, the preliminary risk rating for C4S2 water and fine-loamy soils is **Low (L).**

8) From Table 4.16.5, the listing for Map Unit 147 is located.

9) Examination of the table for risk factors associated with the map unit number indicates:
   - natural soil SAR risk and EC risk = Low;
   - depth to bedrock risk = Low;
   - permeability risk = Moderate;
   - erosion risk = Moderate; and,
   - slope risk = Moderate to High.

10) Even though the water quality and soil characteristics indicate that, with adequate leaching of salts from the root zone, the preliminary risk for this land application area is low, the erosion factor and particularly the excess slope steepness, modifies the overall risk for land application on this area to ***moderate to high risk.***

As stated previously, the risk assessment for land application is made for native soils and vegetation without other management options that can lower risk or mitigate risk factors. The only management assumption made is that leaching of salts below the root zone occurs.

4.16.3.2 Land Application Management Options

Once the feasibility for potential success of land application as a CBM water management option is determined for native soil and vegetation conditions, several management options exist that can be used to prevent problems associated with land application, to lower potential risk associated with land application, or to mitigate potential land application problems. Following are discussions on land application equipment, chemical and organic amendments, leaching requirement calculations, and potential vegetation alternatives.

4.16.3.2.1 Land Application Equipment

Several options are available for application of CBM waters to lands. The selection of the option best suited for a land application operation will be based on the desired land application efficiency, cost of equipment, terrain and slope, and the area available for land application. Land application equipment may include center pivot irrigation systems, side roll systems, big gun sprinklers, hand-move pipe, and solid set irrigation equipment. Other land application possibilities, such as misters and atomizers, were discussed in previous sections.

4.16.3.2.1.1 Center Pivot Sprinkler Systems

4.16.3.2.1.1.1 General Description

Center pivot sprinkler systems are capable of applying large quantities of water to land application sites in a relatively short period of time. The systems are capable of supplying from 600-900 gpm for a full 7-tower, quarter-section (125 acres irrigated) system. Because the system moves in a circle, the inner sprinkler heads close to the pivot point are spaced and sized to apply less water than the heads placed on the towers farther out on the system, resulting in a uniform application rate along the full length of the pivot system. These systems can be designed to apply varying rates, but for an agricultural application they typically apply approximately 1 inch of water per cycle, or approximately 3.4 million gallons per application for a 125-acre pivot. Center pivot nozzles can be sized to regulate the size of the water droplet that will hit the ground. The size of the water droplet can influence infiltration rates significantly and the irrigation dealer should be consulted on droplet size when designing the system for the operator. Smaller systems with fewer towers can be designed. For example, a two-tower system would irrigate approximately 10 acres and could apply between 50-75 gpm at a 1-inch application rate.

4.16.3.2.1.1.2 Advantages/Benefits

Center pivots are the least labor-intensive sprinkler application equipment. They are also very efficient, often approaching 90-95% efficiencies where the majority of the pumped water reaches the soil, and evaporative losses are minimal. Pivot systems work with relatively low pressure, they routinely apply approximately one inch of water per rotation, and they are capable of applying from 600-900 gpm, depending upon the size of the system. Center pivots are designed to be very uniform in application and are the best sprinkler unit to insure that leaching of salts occurs through the root zone. Once installed, center pivots require relatively little labor to maintain and operate. The systems are fully automated with built-in shutoff safeguards should the pivot become stuck or water pressures drop.

4.16.3.2.1.1.3 Disadvantages/Detriments

A major drawback to the use of pivots, and land application in general, is that this process is seasonal. That is, after the soils freeze, land application cannot be continued. Because of the seasonal aspect, expensive off-season storage would be required. Another drawback to pivots is the fact that they require relatively flat terrain (generally slopes less than 6% to control runoff) to operate. In addition, pivots are significantly more expensive than other sprinkler equipment. Another potential drawback to center pivots is the area available for land application. A single, 7-tower, 125-acre (quarter section) pivot is much less expensive than several 2-tower (20 acre) pivots. While larger systems have potential in the WHCW and SHCW basins, very little terrain exists within the DHCW drainage that will accommodate the use of larger center pivots, however smaller pivots may be utilized.

Most of the systems in operation today are electrically powered, and the lack of a uniform power grid in the basin could be a major drawback to the use of pivots. However, some manufacturers still make hydraulically-driven pivots that move by water or oil hydraulics. The power requirements for these pivots would thus be at the pump only.

4.16.3.2.1.1.4 Permitting and Regulatory Requirements

Currently, few permitting requirements exist for land application operations. The WSEO permits land application as either surface water disposal or ground water disposal. If the land application occurs directly at the end of pipe or wellhead without storage, land application is permitted as "irrigation" on the ground water permit for the well(s). If water is stored for off-hour or off-season in a pond, the land application must be permitted as surface water disposal and must be permitted using WSEO Form SW-3 and accompanying certified map. If an agronomic crop is to be grown, the use must be marked as "irrigation". No restrictions have been placed to date on the quality of water suitable for land application.

4.16.3.2.1.1.5 Cost Estimates

Tables 4.16.9 and 4.16.10 below summarize the capital and operational cost estimates for center pivot irrigation systems. The cost estimates assume that native vegetation will be irrigated and no special practices will be necessary to successfully irrigate the soils. Costs for special practices, such as amendment application, additional farming, or alternative vegetation are summarized below in other sections. If special practices are necessary, those costs must be added to the land application cost to arrive at a final cost estimate.

The largest pivot system likely utilized in the Three Horses drainage basins will be a maximum of 40 acres in size. This system will apply approximately 250 gpm at a one-inch application rate.

Table 4.16.9
Capital Cost Estimate - Center Pivot Sprinkler System

Item	Unit	Qty.	Unit Cost	Cost	Cost
Engineering/Permitting Etc.					
Characterization, design, and specifications					$25,000
Permits					$5,000
Legal Fees					NA
Construction/Capital Costs					
Off-season/off-hour storage pond					
Excavation	CY	200,000	$1	$200,000	
30ml HDPE liner	SF	450,000	$0.55	$247,500	
Surveying	HR	10	$167	$1,670	
Water Control Struction	LS	1	$3,400	$3,400	
Outfall Structure	LS	1	$3,000	$3,000	
Rock Rip-rap	CY	20	$32	$640	
Misc.	LS	1	$2,000	$2,000	
Center Pivot					
4 tower pivot w/ installation, controls etc	LS	1	$28,000	$28,000	
Piping	FT	1000	$2	$2,000	
Pump	LS	1	$4,000	$4,000	
Intitial Field Preparation					
Brush/shrub clearing	ACRE	40	$45	$1,800	
Minor Land Leveling	ACRE	40	$100	$4,000	
Disking	ACRE	40	$40	$1,600	
Construction/Capital Subtotal #1				**$497,610**	
Engineering @ 10%				$49,761	
Subtotal #2				**$547,371**	
Contingency @ 15%				$82,106	
Construction/Capital Total				**$629,477**	**$629,477**
TOTAL PROJECT COSTS					**$659,477**

Assumptions: Water disposal rate = 500 gpm x 4 days/week x 35 weeks
System size = 40 acres
Agronomic crop is irrigated
Management scenario assumes amendments are not used. If amendments are needed, their cost must be included in the cost per 1000 gallons calculation.

Annualized capital cost: 4% @ 20 years = $659,477 x 0.07358 = $48,524

Table 4.16.10
Operations Cost – Center Pivot Sprinkler Systems

Item	Unit	Qty.	Unit Cost	Cost
Pivot Op/Maint. Labor	HR	315	$10	$3,150
Benefits @ 24%	LS	1	$756	$756
Maintenance Parts	LS	1	$500	$500
Electricity	KWH	40000	$0.04	$ 1,600
Custom Farming (every 3 years, annualized)				
Roller Harrowing	ACRE	40	$12	$480
Seeding	ACRE	40	$15	$600
Seed - Alfalfa	LB	1600	$0.90	$1,440
Fertilizer	LB	3200	$0.10	$320
Swathing/Baling/Stacking	ACRE	40	$80	$3,200
Misc.	LS	1	$1,000	$1,000
Monitoring Consultant	LS	1	$8,000	$8,000
Laboratory	LS	1	$2,500	$2,500
Operation/Maintenance Subtotal				**$23,546**
Minus Crop Value	TON	120	$75	-$9,000
OPERATION AND MAINTENANCE TOTAL				**$14,546**

Total Annual Cost: annualized capital plus operations = $(48,524 + 14,546) = $63,070/year

Cost per 1000 gallons of water = $63,070/100,000 gallons

= $0.63/1000 gallons

4.16.3.2.1.2 Big Gun, Mobile Big Gun or Traveling Big Gun Sprinklers

4.16.3.2.1.2.1 General Description

While center pivot sprinklers have multiple sprinkler heads, big gun systems operate with a single, high-impact, large output sprinkler head. The sprinkler head is mounted on a center feed pipe and oscillates in a circle around the feed system. Like most oscillating lawn sprinklers, the water can be directed to spray in any arc configuration, and the head can usually be adjusted to spray at higher or lower angles. Big gun systems are designed to sit in one location until the desired amount of water has been applied. They can then be moved to new locations by towing with a tractor or other vehicle. Traveling Big gun systems are designed to follow a cable that has been stretched over the proposed irrigation area. The cable and the feed line are flexible and roll up with the system as it moves along the cable.

4.16.3.2.1.2.2 Advantages/Benefits

These systems are capable of spreading water over large areas (several acres per setting), and they have an advantage over center pivots in that they can be placed in land application areas that will not accommodate pivots. Big gun systems typically can apply water at approximately 150-300 gpm, depending upon size. Big gun systems are typically much less expensive than center pivots.

4.16.3.2.1.2.3 Disadvantages/Detriments

Big gun systems have the disadvantage of being much less efficient that center pivot in terms of application. Because big guns shoot the water into the air, rather than spray it onto the ground, a significant portion of the pumped water is lost to evaporation. Depending on wind speed, generally only 60-80% of the pumped water reaches the soil. While the evaporation may be a good method to dispose of water, the evaporation may result in the concentration of salts and sodium on the soil beneath the big guns. In addition, wind will significantly alter the application pattern of big gun systems, with more water being applied to the downwind side of the system than to the upwind side.

Because they are less efficient, big guns are much more difficult to achieve uniform leaching of salts through the root zone, a management tool that is absolutely required for land application with CBM waters. Because the heads are large output heads, they put out large water droplets that can impact surface infiltration rates by sealing soil surface pores and promoting runoff rather than infiltration. The big gun systems are also more labor intensive than center pivot systems, since they require frequent monitoring and need to be moved often. Because the system requires moving often, problems of towing the system across wet soils can occur on systems set to irrigate a full-circle pattern. As with other land application systems, this process is seasonal and would require off-season storage.

4.16.3.2.1.2.4 Permitting and Regulatory Requirements

Permitting and regulatory requirements are the same as for center pivots.

4.16.3.2.1.2.5 Cost Estimates

Table 4.16.11 and 4.16.12 summarize the estimated capital and operational costs of using big gun sprinklers for land application. As with the center pivots, the cost estimates assume that no special management practices are needed, and that native vegetation is irrigated.

Special management costs must be added into these costs to determine the overall cost of this land application system. This cost estimate is based upon a system that applies 150 gpm over a 125-foot radius (+/- one acre), and application rates per site setting are maintained at one inch per application before moving the system. Assuming an application efficiency of 70%, the system would need to be moved approximately every four hours.

Table 4.16.11
Capital Cost Estimate – Big Gun Sprinkler Systems

Item	Unit	Qty.	Unit cost	Cost	Cost
Engineering/Permitting Etc.					
Characterization, design, and specifications					$23,000
Permits					$5,000
Legal Fees					NA
Construction/Capital Costs					
Off-season/off-hour storage pond					
Excavation	CY	105,000	$1	$105,000	
30ml HDPE liner	SF	180,000	$0.55	$99,000	
Surveying	HR	8	$167	$1,336	
Water Control Struction	LS	1	$3,400	$3,400	
Outfall Structure	LS	1	$3,000	$3,000	
Rock Rip-rap	CY	15	$32	$480	
Misc.	LS	1	$2,000	$2,000	
Big Gun Sprinkler					
System with cable travel	LS	1	$14,000	$14,000	
Piping	FT	1000	$2	$2,000	
Pump	LS	1	$4,000	$4,000	
Construction/Capital Subtotal #1				**$234,216**	
Engineering @ 10%				$23,422	
Subtotal #2				**$257,638**	
Contingency @ 15%				$38,646	
Construction/Capital Total				**$296,283**	**$296,283**
PROJECT COST TOTAL					**$324,283**

Assumptions: Water disposal rate = 150 gpm x 6 days/week x 35 weeks
System size = 20 acres
Native vegetation is irrigated
Chemical amendments are not used. If chemical amendments are needed, their cost must be included in the cost per 1000 gallons calculation.

Annualized capital cost: 4% @ 20 years = $324,283 x 0.07358 = $23,858

Table 4.16.12
Operations Cost – Big Gun Sprinkler Systems

Item	Unit	Qty.	Unit Cost	Cost
System Op/Maint. Labor	HR	1000	$10	$10,000
Benefits @ 24%	LS	1	$2,400	$2,400
Maintenance Parts	LS	1	$250	$250
Electricity	KWH	32000	$0.04	$1,280
Misc.	LS	1	$500	$500
Monitoring Consultant	LS	1	$5,500	$5,500
Laboratory	LS	1	$2,500	$2,500
Operation/Maintenance Total				**$22,430**

Total Annual cost = annualized capital cost per operations = $(23,858 + 22,430) = $46,288/year

Cost per 1000 gallons of water = $46,288 / 45,000 gallons

= $1.03 /1000gallons

4.16.3.2.1.3 Hand Move Irrigation Systems

4.16.3.2.1.3.1 General Description

Hand move irrigation pipe is another possible alternative to mobile sprinkler systems. While much more labor intensive, they can be placed in almost any configuration desired, and are much less expensive to purchase than other systems. Like the big gun systems, hand move sprinkler efficiencies are less than the center pivot since they spray the water in the air rather than down to the ground. Application capacities and rates are very flexible with these systems and are governed by the total length of the hand move system, number of sprinkler heads, and nozzle sizes. Generally, these systems irrigate a 50-to-80 foot radius circle, depending upon flow rates and sprinkler spacing.

4.16.3.2.1.3.2 Advantages/Benefits

Because of the steep and heavily dissected terrain, particularly within the DHCW, hand move pipe may be a good choice operationally for land application systems. The pipe system is very flexible and can be placed down ridge tops and along the upper sideslopes of the ridges. Again, the length can be easily adjusted and is governed by the size of pump used to provide the necessary pressure and flow volumes. Application rates can be adjusted so that the systems only require moving periodically.

4.16.3.2.1.3.3 Disadvantages/Detriments

The application efficiency of hand move pipe is much lower than for center pivots but slightly higher than for big gun systems because the water is applied closer to the ground. Generally, the application efficiency of hand move sprinkler systems is 70-85%, depending on application rate, nozzle and droplet size, and wind speed and direction. The system is very labor intensive, requiring two operators to move the pipe. In addition, the system is suited for sites that have lower water disposal requirements, since the application area is much smaller than for center pivot and big gun systems. It is likely that hand move systems are suitable to serve a single well, whereas the other systems (particularly the center pivot system) can serve multiple wells. As with the other land application systems, the hand move system will be seasonal.

4.16.3.2.1.3.4 Permitting and Regulatory Requirements

The permitting and regulatory requirements for this system are the same as for the other sprinkler irrigation systems.

4.16.3.2.1.3.5 Cost Estimates

Table 4.16.13 and 4.16.14 summarize the estimated capital and operational costs of using a hand move sprinkler irrigation system for land application. The costs assume that special management practices are not being used. When such special practices are necessary, their costs must be added into these costs.

The estimates were based on a system that applies the water over a 50-foot radius and is 1000 feet long. The land application area slightly exceeds two acres per setting, and water is applied at a rate of one inch per 10 hour setting at a rate of 100 gpm.

Table 4.16.13
Capital Cost Estimate – Hand Move Irrigation Pipe

Item	Unit	Qty.	Unit cost	Cost	Cost
Engineering/Permitting Etc.					
Characterization, design, and specifications					$20,000
Permits					$5,000
Legal Fees					NA
Eng./Permitting Subtotal					**$25,000**
Construction/Capital Costs					
Off-season/off-hour storage pond					
Excavation	CY	105,000	$1	$105,000	
30ml HDPE liner	SF	180,000	$0.55	$99,000	
Surveying	HR	8	$167	$1,336	
Water Control Struction	LS	1	$3,400	$3,400	
Outfall Structure	LS	1	$3,000	$3,000	
Rock Rip-rap	CY	15	$32	$480	
Misc.	LS	1	$2,000	$2,000	
Hand Move Sprinkler System					
System including pipe, heads, nozzles, e	LS	1	$16,500	$16,500	
Piping	FT	1000	$2	$2,000	
Pump	LS	1	$4,000	$4,000	
Construction/Capital Subtotal #1				**$236,716**	
Engineering @ 10%				$23,672	
Subtotal #2				**$260,388**	
Contingency @ 15%				$39,058	
Construction/Capital Total				**$299,446**	**$299,446**
PROJECT TOTAL COST					**$324,446**

Assumptions: Water disposal rate = 150 gpm x 6 days/week x 35 weeks = 45,000,000 gal
System size = 20 acres
Native vegetation is irrigated
Chemical amendments are not used. If chemical amendments are needed, their cost must be included in the cost per 1000 gallons calculation.

Annualized capital cost: 4% @ 20 years = $324,446 x 0.07358 = $23,873

Table 4.16.14
Operations Cost – Hand Move Irrigation Pipe

Item	Unit	Qty.	Unit Cost	Cost
System Op/Maint. Labor	HR	1500	$10	$15,000
Benefits @ 24%	LS	1	$2,400	$2,400
Maintenance Parts	LS	1	$350	$350
Electricity	KWH	32000	$0.04	$1,280
Misc.	LS	1	$500	$500
Monitoring Consultant	LS	1	$5,500	$5,500
Laboratory	LS	1	$2,500	$2,500
Operation/Maintenance Total				**$27,530**

Total Annual cost = annualized capital cost per operations = $(23,873 + 27,530) = $51,403/year

Cost per 1000 gallons of water = $51,403 / 45,000 gallons
= $1.14/1000 gallons

4.16.3.2.1.4 Other Land Application Equipment

Additional irrigation equipment may be considered by various companies, including solid set irrigation pipe and side roll irrigation systems. These systems have similar advantages and disadvantages of the systems described above and should be evaluated on an individual basis, as necessary. Other potential land application equipment could include atomizers or misters. These units were described previously in Sections 4.5 – Enhanced Evaporation Using Atomizers and 4.6 – Enhanced Evaporation Using Misters. As noted, their primary goal is the evaporation of water. Because they shoot the water into the air to promote evaporation, they are very inefficient as a land application tool. Salts and sodium may be concentrated under these systems, just as they would be in an evaporation pond, and the application pattern is dependent upon the wind speed and wind direction. It is nearly impossible to achieve uniform leaching of salts through the root zone with this type of equipment.

4.16.3.3 Chemical and Organic Amendments

4.16.3.3.1 Amendment Types

Previous sections on soil characteristics described the effects of high sodium, high salinity water on soils in detail. While that discussion was provided for operators to be able to assess their risk associated with land application of CBM waters, it also serves to provide the information necessary for determining if risk can be lowered by the use of soil amendments, or to determine if adverse effects of the use of CBM waters for land application can be mitigated.

As described previously, the primary effect of high sodium on soils, particularly medium and fine-textured soils, is that the sodium adsorbs on to the soil exchange complex and causes the soil clay to swell or to disperse. The use of amendments can be applied to prevent sodic soils from forming or to reclaim soils that have become sodic due to the application of CBM waters. It is also important to initially note that the reclamation of sodic soils is not an easy or efficient process, and the costs of chemical amendments may become prohibitive.

In order to mitigate the effects of sodium on soil clays, the sodium must be replaced on the soil exchange complex by other cations, usually calcium, that do not promote swelling. The exchange sodium is soluble and must be leached from the soils. It is very important to recognize that swelling of soil clays is a reversible process, and chemical amendments can be used, under the right conditions, to mitigate the swelling. However, if land application waters have actually caused soil clays to disperse and the clays translocate to fill soil pores, this process is not reversible by the use of chemical amendments.

Several traditional soil amendments have been used in irrigation agriculture and also for various mine land reclamation projects to replace sodium on the exchange complex. Following is a listing and general description of the readily available amendments that have been utilized for this purpose.

The effectiveness of these various amendments in relation to CBM waters is discussed. Only amendments available for use in alkaline environments are presented here for discussion.

Gypsum ($CaCO_4 \cdot 2H_2O$) is the most commonly used amendment, mainly because of its low cost. Surface applied gypsum generally increases infiltration and can reclaim sodic soils to some extent. But, because gypsum has a relatively low solubility, more time and water are required for reclamation than with other amendments. Mixing gypsum into the soils is necessary to accelerate the reclamation process. Following is the general chemical reaction of gypsum in sodic soils:

$$2NaX + CaSO_4 <> CaX_2 + Na_2SO_4$$

By this reaction, sodium on the exchange complex (2NaX), when gypsum is applied and mixed into the soil, is replaced by calcium on the exchange complex (CaX_2). When this reaction occurs, sodium salts (Na_2SO_4) are produced that must be leached from the root zone.

Phosphogypsum is a by-product of the phosphate fertilizer industry. The solubility product of gypsum is the same whether in the form of mined gypsum or phosphogypsum; however, the surface area (at any given fragment size) of phosphogypsum is larger than that of mined gypsum and, therefore, the dissolution rate (rate particles dissolve) is higher. Because of the higher dissolution rate, phosphogypsum has proved more effective than mined gypsum in maintaining a high infiltration rate. As with mined gypsum, phosphogypsum is relatively inexpensive. Phosphogypsum does have one characteristic that needs to be checked before purchase. Phosphogypsum is produced when phosphate is removed from rock phosphate (calcium apatite rock). Rock phosphate can have low levels of radium present and the resultant phosphogypsum can also have low levels radium. The ability of an operator to use phosphogypsum repeatedly will depend on the level of radium in the phosphogypsum and on the ability to leach the phosphogypsum through the root zone. Generally, the radium levels are very low and potential risks associated with radium are also extremely low.

Both mined gypsum and phosphogypsum have one major drawback for use in the CBM industry to reclaim sodic soils. The CBM waters tend to be very high in bicarbonate content. Bicarbonate waters can cause the calcium from the gypsum to precipitate as calcium carbonate. This results in two potential problems:

1) the calcium carbonate can plug pore spaces restricting water flow, and
2) the calcium for replacement of sodium on the exchange complex is tied up with the carbonates and thus is unavailable for exchange.

The result is that gypsum reclamation efforts may be significantly less effective than is needed to reclaim the sodic soils or to prevent sodic soils from occurring.

Calcium Chloride ($CaCl_2 \cdot H_2O$) requires much less time and water for reclamation than needed for gypsum because of its high solubility that produces a leaching solution of high electrolyte concentration. The high electrolyte concentration that is efficient at replacing sodium on the exchange complex, particularly in soils with very high ESP levels, can result in increased water intake rates. The chemical reaction in soils with calcium chloride is as follows:

$$2NaX + CaCl_2 <> CaX_2 + NaCl_2$$

In this case, the salt produced by this action is sodium chloride (NaCl) and also requires leaching from the root zone.

One of the major drawbacks with the use of calcium chloride as an amendment is that its costs are significantly higher than the costs of gypsum. While little research has focused on the effects of high bicarbonate waters on calcium chloride, the CBM water can also result in the precipitation of calcium as carbonates, again resulting in possible plugging of soil pores by carbonates and low amendment efficiencies due to the unavailability of calcium for exchange.

Magnesium Chloride ($MgCl_2 \cdot H_2O$) has also been considered for use as a chemical amendment in sodic soils. Like calcium chloride, magnesium chloride requires much less time and water for reclamation than is needed for gypsum because of its high solubility that produces a leaching solution of high electrolyte concentration. This process is efficient at replacing sodium and can directly result in increased water intake rates. The chemical reaction in soils is as follows:

$$2\ NaX + MgCl_2 <> MgX_2 + NaCl_2$$

As with calcium chloride, the salt produced by this action is sodium chloride which requires leaching from the system. In addition to the dry form of magnesium chloride, it is readily available in concentrated liquid form since it is commonly used as a dust suppressant on gravel roads. While the cost of magnesium chloride is higher than gypsum, it is often less costly than calcium chloride. As with other amendments, magnesium chloride also suffers from the "dilution" effect when magnesium is precipitated as a carbonate when the land application water is dominated by bicarbonates.

The use of magnesium chloride also has another drawback. While researchers have significant difficulty explaining the process mechanism, excess magnesium can result in the plugging of soil pores over time and a reduction in infiltration rates, making it less effective than calcium amendments. Theses processes have been observed following amendment of bentonitic soils in both Montana and Wyoming. Initial results of the use of this amendment are often very encouraging, however, after time, the infiltration of these magnesium amended soils can decrease significantly. For this reason, soil taxonomy definitions include magnesium as a qualifier when defining the properties of sodium affected soils. However, due to its apparent short-term effectiveness, some consideration of this amendment should be evaluated.

The use of **Sulfur (S) and Sulfuric Acid (H_2SO_4)** as chemical amendments to reclaim or mitigate sodic soils requires the presence of calcium carbonate minerals in the soil. Sulfur is often applied in conjunction with gypsum for use to reclaim irrigated soils. The carbonate minerals may be naturally occurring, result from the use of other amendments, or be applied in the form of various calcium carbonate sources. The use of sulfur alone or in combination with gypsum is a very slow process. Following is the chemical reaction of sulfur in soils for the reclamation of sodic soils:

1) $2S + 3O_2 <> 2SO_3$ (microbiological oxidation)

2) $SO_3 + H_2O <> H_2SO_4$

3) $H_2SO_4 + CaCO_3 <> CaSO_4 + CO_2 + H_2O$[8]

4) $2NaX + CaSO_4 <> CaX_2 + Na_2SO_4$

Without calcium carbonate or gypsum in the soils, the use of sulfur or sulfuric acid is a waste of time. The above steps outline why sulfur used alone is a very slow process for reclamation. Sulfur is converted by microbiological oxidation (step 1) and then combined with water to form sulfuric acid (step 2). The microbiological oxidation is a very slow process and proceeds independently of the presence of water. The sulfuric acid that is formed in step 3 is then capable of dissolving calcium carbonate and freeing the calcium for exchange with sodium (step 4).

The efficiency of steps 3 and 4 will be governed by the availability of the calcium carbonate. As with the application of gypsum, the salt produced is sodium sulfate and requires leaching below the root zone. The only significant advantage of the use of sulfur is its low costs, however, due to its slow reaction capabilities, it is not an ideal chemical amendment.

Obviously the direct application of sulfuric acid to reclaim sodic soils is much more efficient than the application of sulfur. Steps 1 and 2 are not required, so the overall speed of reaction is much faster than with sulfur alone. Sulfuric acid also produces a high electrolyte concentration that promotes water intake but also has the ability to solubilize aluminum and iron hydroxyl compounds that promote flocculation and stabilization of soil structure. As with sulfur, however, the use of sulfuric acid requires the presence of calcium carbonate in the soils to supply a calcium source for exchange.

The other disadvantage of sulfuric acid is its high costs and the need to utilize special application equipment because of its extreme acidic nature. As with the other chemical amendments discussed, the use of high bicarbonate waters may result in the precipitation of some calcium as carbonate, significantly lowering reclamation efficiencies. This results in the necessity to continually reapply the sulfuric acid over time if an area continues to receive CBM waters. Continual application of sulfuric acid can also lead to soil acidification over time and to possible adverse effects on vegetation due to the acidification.

Recent discussion on the possible use of "sulfur burners" to produce sulfuric acid from sulfur may make the cost of sulfuric acid much cheaper. That is, the sulfur burner ignites elemental S and ultimately converts the sulfur to acid. This process is apparently less costly than for the purchase of sulfuric acid in totes or bulk form. However, the process still requires the presence of calcium carbonate in the soils or the application of other chemical amendments as described above.

Ground limestone, carbide lime, and sugar beet lime are normally not considered effective for reclaiming soils in alkaline earth environments such as those that exist in the DHCW. However, various lime sources can be added in conjunction with sulfuric acid if carbonates are naturally low in the soils in relation to the sodium content. The solubility of lime in water is very slow in an alkaline environment. However, lime will dissolve readily in the presence of acid.

Carbide lime and sugar beet lime have the same advantages as phosphogypsum; i.e., while they have the same solubility product as ground limestone, their larger surface area results in a much higher dissolution rate. In addition, both products are produced as by-products of other industries and are readily available at relatively low cost. Carbide lime is particularly attractive because it has a very high purity, often exceeding 95%. The purity (calcium carbonate content) of ground limestone and sugar beet lime is much lower than carbide lime.

In terms of management of chemical amendments, it is likely that a combination of amendments may be necessary due to efficiencies and cost factors. In general chemical reclamation efficiencies are: $\mathbf{CaCl_2 > H2SO4 + CaSO_4 = CaCl_2 + CaSO_4 > CaSO_4 + S > CaSO_4 > S}$. Again, all of these amendment efficiencies can be expected to be lower when using high bicarbonate waters. It is also known that pulsed water applications, rather than continual (ponded or saturated) water may be more efficient for reclamation.

Finally, the use of organic amendments may have some merit for reclamation of sodic soils. Organic amendments work to flocculate or bind soil particles together increasing the ability of water to flow through the soils. Organic amendments may include livestock manure or municipal bio-solids. Other organic amendments, such as hay or straw, will have little effect on the binding of soil particles.

4.16.3.3.2 Calculation of Chemical Amendment Requirements

In order to calculate the quantity of amendments needed to reclaim a sodic soil or to prevent a sodic soil from forming, it is necessary to know the ESP and the CEC of the soil in millequivalent per 100 gram (meq/100 g) units or to estimate the desired ESP of the soil after land application. Assume that a soil contains 8 meq/100g of exchangeable sodium and has a CEC of 20 meq/100g. The ESP would then be 40 (8/20 x 100). Assuming a goal of reducing the ESP to 10 or less, approximately 6 meq/100g of sodium will need to be replaced (2/20 x 100 = 10). Therefore, assuming 100% efficiency, the amendment chosen must be applied at a replacement rate of 6 meq/100g. Table 4.16.15 provides a summary of the approximate tonnage of selected chemical amendments necessary to replace 1 meq/100g of sodium on the exchange complex.

Table 4.16.15
Tons per Acre-Foot of Amendments Required to Replace Sodium

Exchangeable Sodium meq/100	Gypsum Tons/A-F	Sulfur Tons/A-F	Sulfuric Aci Tons/A-F	Limestone Tons/A-F	Calcium Chloride Tons/A-F	Magnesium Chloride Tons/A-F
1	1.7	0.3	1.0	1.0	1.1	1.0
2	3.4	0.6	2.0	2.0	2.2	1.9
3	5.2	1.0	2.9	3.0	3.3	2,8
4	6.9	1.3	3.9	4.0	4.4	3,8
5	8.6	1.6	4.9	5.0	5.5	4.7
6	10.3	1.9	5.9	6.0	6.6	5.6
7	12.0	2.2	6.9	7.0	7.7	6.6
8	13.7	2.6	7.8	8.0	8.8	7.5
9	15.5	2.9	8.8	9.0	9.9	8.5
10	17.2	3.2	9.8	10.0	11.0	9.4

Obviously, amendments are not 100 percent efficient. To counter the inefficiency, additional amendments will need to be applied and incorporated. As a rule of thumb, the amendments should be increased by at least 25 percent.

4.16.3.3.3 Amendment Application Techniques and Equipment

Chemical amendments must be applied uniformly to achieve efficient replacement of sodium on the exchange complex. In general, the amendments must be incorporated into the soil to be effective. It is well documented that surface applied amendments without incorporation are much less effective.

The surface area of the amendments is very important as to their ability to dissolve. All solid amendments must be ground, usually to minus 40 mesh or finer, to be most effective. Larger particles do not dissolve readily and can be easily coated with iron or aluminum hydroxyl compounds, rendering them inert for exchange processes.

Equipment must be capable of laying the amendments down onto the soil in a uniform pattern, just as agronomists try to uniformly spread fertilizer. In addition, even though application rates may be large, the actual quantity present on the soil will not appear substantial. For example, a uniform application of 20 tons per acre of phosphogypsum will appear as a dusting on the ground (less than 1/16 inch). Equipment such as manure spreaders are often used to apply chemical amendments; however, they are not recommended because they are incapable of spreading the amendment with accuracy or uniformity. Bulk fertilizer spreaders work more efficiently than manure spreaders, but are not generally designed to handle the finely ground materials without plugging. That is, the belt system that moves the material to the back of the spreader is narrow, and oftentimes the fine materials have difficulty dropping to the belt. Equipment such as road sand spreaders are very efficient amendment applicators. They operate in a manner similar to the bulk fertilizer spreaders, but have a much wider belt to move amendments to the spreader. They drop the amendment immediately to the ground in a consistent and uniform width and pattern.

Once application rates are calculated, the spreader must be field calibrated to apply that application rate. This should be accomplished by laying out a known area and the spreader should be filled with a known quantity of amendment. For example, if the spreader is filled with two tons of amendment, and the application rate is 20 tons per acre, an area of 0.1 acre should be laid out, and the operator should adjust the application according to that area.

Once the amendments are spread uniformly, they should be incorporated into the soil immediately to prevent blowing by the wind. It is important to get the amendments into as finely worked soil as possible to increase the exchange efficiency. This can be accomplished by ripping the soil on a 12-inch wide pattern to a depth of at least 12 inches, using dozer-mounted or blade-mounted rippers. Following ripping, the area should be disked. While agricultural disks may be suitable for some soils for disking the amendments, construction grade disks (such as the disked manufactured by Rome) are better suited for disking. The disking may require several passes to complete incorporation.

The application of sulfuric acid, if incorporated into the soils directly, requires special application equipment and special protective clothing and headgear must be utilized when handling this material. Sulfuric acid is extremely corrosive and will quickly deteriorate strong materials such as carbon steel. Usually, sulfuric acid equipment is made of stainless steel or plastic that is resistant to corrosion. The application equipment is similar looking to equipment used to apply anhydrous ammonia that includes tubes flowing to the backside of chisels located behind the acid storage unit. Chisel shanks need to be closely spaced to apply the acid uniformly.

Alternatively, the sulfuric acid is most efficiently, and cheaply, applied through the irrigation system. However, as with the other application methods, the acid is very corrosive and must be applied through plastic pipelines. Nozzles also have to be plastic and contain no steel, brass, copper, or aluminum fittings. Acid applied in this manner will allow bicarbonate to evolve as CO_2 and will convert the sodium bicarbonate to sodium sulfate salts. Acid is injected into irrigation lines via venturi systems or chemical feed pumps.

4.16.3.3.4 Chemical Amendment Costs

Because the use of chemical amendments and the type of amendment used will be extremely variable, costs of amendments and their application costs were based on a per acre cost. Since center pivot land application is the most efficient form of land application, the costs of amendments related to 1000 gallons of disposed water was calculated. Tables 4.16.16 and 4.16.17 summarize those costs. If these costs are incurred, they must be added to the cost of land application to fully evaluate the overall cost of land applying CBM waters.

Table 4.16.16
Estimated Chemical Amendment Costs

Item	Unit	Qty.	Unit Cost	Cost
Gypsum				
Amendment FOB Gillette, WY	Tons/Acre	14	$65	$910
Haul to Site	Tons/Acre	14	$8	$112
Application	Acres	1	$40	$40
Incorporation (2 passes)	Acres	1	$80	$80
Cost Per Acre				**$1,142**
Phosphogypsum				
Amendment FOB Gillette, WY	Tons/Acre	12.5	$48	$600
Haul to Site	Tons/Acre	12.5	$8	$100
Application	Acres	1	$40	$40
Incorporation (2 passes)	Acres	1	$80	$80
Cost Per Acre				**$820**
Calcium Chloride				
Amendment FOB Gillette, WY	Tons/acre	7.2	$290	$2,088
Haul to Site	Tons/Acre	7.2	$8	$58
Application	Acres	1	$40	$40
Incorporation (2 passes)	Acres	1	$80	$80
Cost Per Acre				**$2,266**
Magnesium Chloride (Dry)				
Amendment FOB Gillette, WY	Tons/Acre	6.4	$135	$864
Haul to Site	Tons/Acre	6.4	$8	$51
Application	Acres	1	$40	$40
Incorporation (2 passes)	Acres	1	$80	$80
Cost Per Acre				**$1,035**
Sulfur				
Amendment FOB Gillette, WY	Tons/Acre	2.8	$52	$146
Haul to Site	Tons/Acre	2.8	$8	$22
Application	Acres	1	$40	$40
Incorporation (2 passes)	Acres	1	$80	$80
Cost Per Acre				**$288**
Sulfuric Acid (66%)				
Amendment FOB Gillette, WY	Tons/Acre	8.9	$300	$2,670
Haul to Site	Tons/Acre	8.9	$12	$107
Incorporation (injection)	Acres	1	$255	$255
Cost Per Acre				**$3,032**
Calcium Carbonate (ground limestone)				
Amendment FOB Gillette, WY	Tons/Acre	8.5	$112	$952
Haul to Site	Tons/Acre	8.5	$8	$68
Application	Acres	1	$40	$40
Incorporation (2 passes)	Acres	1	$80	$80
Cost Per Acre				**$1,140**
Carbide Lime				
Amendment FOB Gillette, WY	Tons/Acre	6.3	$25	$158
Haul to Site	Tons/Acre	6.3	$8	$50
Application	Acres	1	$40	$40
Incorporation (2 passes)	Acres	1	$80	$80
Cost Per Acre				**$328**
Sugar Beet Lime				
Amendment FOB Gillette, WY	Tons/Acre	7.8	$42	$328
Haul to Site	Tons/Acre	7.8	$8	$62
Application	Acres	1	$40	$40
Incorporation (2 passes)	Acres	1	$80	$80
Cost Per Acre				**$510**

Assumptions: Tonnage adjusted for purity and efficiency
Custom application and incorporation
Amendment calculated to replace 5 meq/100g sodium on exchange complex

Table 4.16.17
Amendment Costs per 1000 Gallons – Center Pivot Land Application

Amendment Type	Amendment 1 Costs	Amendment 2 Costs	Consulting,Etc. Costs	Total Costs	Cost Per 1000 Gallons
Gypsum	$ 45,680		$ 40,000	$ 85,680	**$ 0.85**
Phosphogypsum	$ 32,800		$ 40,000	$ 72,800	**$ 0.72**
Calcium Chloride	$ 90,640		$ 40,000	$ 130,640	**$ 1.30**
Magnesium Chloride	$ 41,400		$ 40,000	$ 81,400	**$ 0.81**
Sulfur + Gypsum	$ 11,520	$ 45,680	$ 40,000	$ 97,200	**$ 0.96**
Sulfuric Acid	$ 121,280		$ 40,000	$ 161,280	**$ 1.60**
Sulfuric Acid + Calcium Carbonate	$ 121,280	$ 45,600	$ 40,000	$ 206,880	**$ 2.05**
Sulfuric Acid + Carbide Lime	$ 121,280	$ 13,120	$ 40,000	$ 174,400	**$ 1.73**
Sulfuric Acid + Sugar Beet Lime	$ 121,280	$ 20,400	$ 40,000	$ 181,680	**$ 1.80**
Sulfuric Acid + Gypsum	$ 121,280	$ 45,680	$ 40,000	$ 206,960	**$ 2.05**

Based upon 40-acre application site, 100,800,000 applied gallons

4.16.3.3.5 Salinity Leaching Requirement

As noted in the risk assessment, it is assumed that salts are leached through the root zone so that salinity is not a concern for vegetative growth. Note from the previous discussions on the effect of sodium on soil infiltration rates that reductions in infiltration rates are likely to occur. When a reduction in infiltration exceeds 25%, it may not be possible to achieve leaching of salts through the root zone without the addition of expensive chemical amendments. While it is possible to reverse soil swelling due to high sodium concentrations, it is not possible to reverse actual dispersion and translocation of clays resulting in soil pore plugging. Very careful assessments must be made as to the potential risk of land application to avoid these problems.

While one of the goals of applying CBM water through land application is to maximize the amount of water applied, the following discussion provides a method for calculating the additional amount of water to apply to leach the salts. This method is called the leaching requirement (LR). The LR has been included within the permeability factor portrayed in Table 4.16.8 as a limiting factor for risk assessment. In general, as soil become finer with more clay, it becomes more difficult to "push" water through the soils for leaching.

For land application planning and risk assessment, the LR can be defined by the concentration of salinity in the root zone that will result in a 10% reduction in productivity for the dominant plant species receiving land application. The equation for LR is as follows:

$$LR = EC_{iw}/5(EC_e) - EC_{iw},$$

where EC_{iw} = electrical conductivity of the irrigation water and EC_e = the level of electrical conductivity in the root zone that results in a 10% reduction in productivity.

To clarify the above equation, an example calculation is provided here. Using Wheat Grass as an example, Figure 4.16.2 – Relative Salt Tolerance of Selected Forage Species indicates that a 10% reduction in productivity can be expected at EC_e = 10,000 µmhos/cm. Assuming land application water with an EC=3,200 µmhos/cm, the LR is as follows:

$$LR = 3.2/\ 5(10)-3.2 = 0.068 \text{ or } 6.8\%.$$

For the case of Wheat Grass, 6.8% water over consumptive use (evapotranspiration) needs to be applied to pass the salts through the root zone. Irrigated grasses will consume through transpiration and evaporation, an average of approximately 0.12 inches of water per day over a seven-month active growing season (21 inches total). Assuming that 8 inches of that water is satisfied through precipitation during the growing season, an additional 13 inches of water must be applied through land application to meet the irrigated grasses water requirements.

4.16.3.3.6 Vegetation Alternatives

Current research is focusing on vegetation that is very salt tolerant, including new varieties of alfalfa and hay barley. In addition, the potential use of hydrophytic plants to reclaim sodic soils is progressing. At this time, no recommendations for new salt tolerant plant species can be made until more research is completed.

4.16.3.3.7 Current Industry Land Application Practices

Several CBM companies have been attempting land application using a variety of techniques. It is apparent that the move to land application is being considered as a major water disposal and beneficial use practice for CBM waters. Most of the operators appear to be developing land application programs with the help of outside consultants.

CBM companies appear to be moving away from the use of atomizers/misters as land application equipment. As described previously, these methods are very inefficient in terms of applied water to the soils, little leaching of salts is expected to occur, and the systems are difficult to manage in terms of application patterns due to winds. Apparently these methods are resulting in the generation of significant salt crusting and very limited leaching of salts, as predicted.

Several companies are utilizing center pivot irrigation systems for land application. The systems range in size from 20 acres for test systems to full-size quarter-section systems. It appears that the majority of these operators are using sulfuric acid (or sulfur burners to generate acid) in conjunction with the application of gypsum products to supply a calcium source. Most of the operators are irrigating native vegetation, with a few considering the production of alfalfa and other forage crops. Results of the effectiveness of these methods are currently unknown. This method requires sufficient leaching of salts to remove the combination of salts applied in the water plus the salts applied as amendments and to allow for soluble sodium to be leached from the system. If soluble sodium is not leached from the system, the sodium/calcium exchange processes are not effective.

It has also been reported that sulfur burners are being used to generate acid to apply directly to soils without the addition of calcium-based amendments. Again, results of these methods are currently not known. However, this technique dissolves natural calcium carbonate in the soils to supply calcium to ameliorate the affects of sodium. If this method is to be used annually on the same soils, calcium-based amendments will have to eventually be applied to the soil, hence the cost of these methods will significantly increase. It should also be noted that acid injected into irrigation lines will convert much of the bicarbonate to CO_2 which is then lost to the atmosphere during spraying. Applied salts then are composed largely of sodium sulfate rather than sodium bicarbonate salts. Acid needs to be injected at a rate sufficient to convert the bicarbonate and to leave sufficient acidity to dissolve available calcium.

Several companies are attempting land application using trailer-mounted big gun applicators. These companies are utilizing larger tracts of land and applying lower quantities (1-12 inches) of CBM water per a given area. Some operators are applying gypsum products at a rate of two tons per acre ahead of the water application. While the gypsum supplies a source of calcium to mitigate the effects of sodium, it is not likely, even with 12 inches of applied water, that sufficient water is being applied to leach the increased salt loads through the soils. The systems are continually being moved, and results of these methods are still unknown. Another company is using numerous big gun systems to supply CBM water without the addition of chemical amendments. The systems appear to apply approximately one inch of water per day and then are moved to a new location. Salt loading and sodium loading at the soil surface are likely, however, and the long-term effectiveness of this method is also unknown at this time.

5. ANALYSIS OF WATER MANAGEMENT ALTERNATIVES AND RECOMMENDED WATERSHED MANAGEMENT PLAN

Section 4 provided information on various water management alternatives and associated reconnaissance level costs estimated to implement these alternatives. For purposes of more easily comparing these water management alternatives, Table 5.1 provides a summary of listing the various alternatives, whether or not they require water management alternatives in conjunction with this alternative, the benefit/advantages in implementing the alternative, the detriments/disadvantages inherent in implement them, and relative cost data. As mentioned previously, it is important to recognize in the review of the cost comparison figures that they represent merely gross conceptual estimates on the various alternatives, that actual costs for implementation could vary considerably from those portrayed in this section, depending upon geographical, geological and market conditions.

Based upon the water management alternatives evaluated, the following general recommendations are made.

A. Those water management alternatives that entail a basinwide solution; i.e., collecting, treating, piping outside of the drainage basins, or mixing with other sources, should not be pursued at this time. Reasons why these basinwide solutions should not be pursued include the following:

- The duration of CBM production in the three watersheds is difficult to predict, and may be relatively brief, as has been demonstrated in the Belle Fourche basin to the east. Within the Belle Fourche basin, CBM wells are already approaching a "mature" status (George 2002) after just five to seven years of production. As such, a stable, long-term financing plan required for the capital infrastructure necessary may prove unattractive to CBM producers who may be reluctant to retire debt over a long period of time when the source of revenue (i.e., CBM) will have been depleted.

- As has been the case over the last year, suppression of the price of energy (and thus price of natural gas) makes the amount of drilling activity and associated CBM well development highly variable. Low energy prices can lead to a decrease in the cost-effectiveness of CBM production. Once water-producing activities at a CBM well commence, "shutting in" the well is more difficult than conventional gas wells, as groundwater levels will return to previous levels in the event of a shutdown in pumping. As a result, the previous water pumping will have gone to little benefit for the CBM operator. Therefore, concerns about the long-term price of natural gas will make CBM operators reluctant to enter into long-term financing plans that address water disposal solutions.

- The amount of water that will be generated over the long term by CBM production is highly variable, and will make the prediction of the sizing of the required capital facilities extremely difficult. Basinwide water management alternatives portrayed in this study (Piping Water to the Powder River for Direct Discharge, Piping Water to the Powder River with Water Treatment, Lake DeSmet Storage Releases) assume almost simultaneous development, which is very unlikely unless natural gas prices rise significantly. Previous predictions on the amount of water estimated to be produced have varied widely, and most have proven to be higher than the actual amount of water produced. The U.S. Department of Interior BLM Draft Environmental Impact Statement on Coal Bed Methane (U.S. Department of Interior, BLM 2002) predicted 10 gpm per well; this study uses 8 gpm per

TABLE 5.1
SUMMARY OF WATER MANAGEMENT ALTERNATIVES

WATER MANAGEMENT ALTERNATIVE	REQUIRES OTHER WATER MANAGEMENT ALTERNATIVES TO FULLY IMPLEMENT?	ADVANTAGES/BENEFITS	DISADVANTAGES/DETRIMENTS	ESTIMATED COST/1000 GALLONS TO IMPLEMENT
Direct Discharge to Channels	No	• Cost effective • Supplements livestock and wildlife water supplies • Recharges shallow and possibly deeper aquifers • Potential to increase forage production along stream • Possibility that much of the actual flow discharged will be lost to evaporation and infiltration	• Metamorphosis of a stream system from ephemeral to perennial • Vegetation changes from fine-bladed to coarser-bladed grasses • Access problems resulting from inadequate or lack of culverts, water crossings, bridges, etc. • Increased amounts of ice buildup along stream during winter • Potential for perennial water in low areas behind spreader dikes • Potentially more active headcutting/erosion & subsequent deposition • Potential for decreased soil permeability with the change in surface water quality • Possibility that downstream landowners will consider CBM flow across their lands as a trespass.	$0.05
Containment-and-Loss Reservoirs	No	• Viability as a (short-term) supply of water for livestock and wildlife • No addition of water to surface and subsequent issues • If built off-channel, few if any issues with downstream irrigation rights • Some potential to recharge shallow aquifers • General permits available from WDEQ for off-channel reservoirs	• Containment structure is highly dependent upon topography and permeability of surface units • Post-CBM production may necessitate the mitigation of structures and reclamation of land • Lands beneath reservoir may eventually contain a high volume of residuals • Little to no use after CBM production has ceased unless reclaimed (off-channel only) • Loss of forage production in area of the containment structure during use & until reclamation completed • Considerable areas of land may be necessary to fully effectuate this method of water disposal • Evaporation rates much higher in summer than winter, requiring additional winter storage	$1.13
Containment-and-Release Reservoirs	No	• Relatively cost-effective • Minimal impact upon existing irrigation, both in the Three Horses areas and along the Powder River in Wyoming and Montana • Opportunities afforded to periodically discharge accumulated dissolved material • Viability as a (short-term) supply of water for livestock and wildlife • Evaporation during the summer months can assist with water dissipation • Potential to recharge shallow aquifers	• Water contained within the reservoirs will have higher concentrations of CBM constituents • Containment structure is highly dependent on topography and permeability of surface units • No assurance that the State of Montana will agree to releases during non-irrigation season • Potential for increased erosion due to large releases over relatively short period of time • Potential for damage to existing soils due to spillage out of channels during periods of release • Post-CBM production may necessitate the mitigation of reservoir areas • Drained-down reservoir areas lacking in vegetation will exist after release periods and prior to refilling	$0.53
Injection	Yes	• Potential to inject large quantities of water for disposal or groundwater storage for future use	• High cost • Potential for high initial investment without achieving the necessary injection volumes • Difficulty in finding suitable receiving aquifers • For injection into previously used wells, possible problems due to poor cementing & mud control • Relatively stringent regulatory requirements due to possible problems with existing water compatibility	$4.90
Enhanced Evaporation Using Atomizers	Yes	• Capability to evaporate substantial amounts of water (up to 80% in summer months) • With proper management, forage and vegetation can be improved • Towers are generally mobile, thus providing flexibility for system operations • Impact areas are relatively small and may avoid many surface runoff issues	• Lack of availability of suitable soils in Three Horses drainage areas • Significant monitoring required of the soils beneath the evaporative facilities • Likelihood of necessary soil additives to assure no degradation of ambient soil quality • Seasonal use only; requires storage or other means of water disposal during the winter • Current lack of knowledge of long-term impacts to soils and vegetation irrigated with atomizer spray	$2.41
Enhanced Evaporation Using Misters	Yes	• Installation of floating systems within reservoir could dramatically reduce soil impacts • May be more operationally feasible during winter conditions • Trailer-mounted misters can allow flexibility in the location of these units	• Efficiency is greatly dependent upon weather conditions and time of season • Expense associated with equipment substantially exceeds that required for passive evaporation • Power requirements can be difficult to meet in remote areas • If used on land, possibility of detrimental effects on soils and forage quantities due to a buildup of the dissolved solids that are released from the evaporated water	$1.93
Piping Water to Other Drainage Basins	No	• Eliminates problem in PRB	• Merely transfers problems to another drainage basin that was not the source of the CBM water	No costs estimated
Piping Water to Powder River for Direct Discharge	No	• Eliminates water problems associated with CBM discharges onto landowners within the Three Horses basins • Only temporary construction disturbance to downstream landowners (vs. possible perpetual disturbance if surface water discharges are allowed) • Eliminates need for storage facility construction • CBM pumps could be easily sized to accommodate system • Could be constructed in phases • Possible hydropower generation at confluence of Three Horses streams with the Powder River	• Very high total capital costs required to implement system • Will require considerable cooperation among CBM companies to participate in regional plan • Large temporary disturbance to lands due to additional pipeline construction • Fluctuation in market conditions will make CBM companies reluctant to enter into long-term contracts for water disposal • No assurance that Montana will accept water of lesser quality than that which it has historically seen in the Powder River at the Moorhead, Montana gaging station • Eliminates possible beneficial use of water within Three Horses basins	$0.24
Water Treatment Using Reverse Osmosis	No	• Produces very high quality water - can reduce EC by 98% • Allows use of produced water for anything from drinking to industrial use • Treatment units can be purchased in package plants, from very small to very large • Can be operated seasonally if necessary • Relatively small portable unit(s) may be configured for use at multiple sites • Flexibility with medium-sized units can be used at a site for several years, then moved to new site	• Relatively high capital and operating cost, and regular operator attention • Loses efficiency with cold water • Produces relatively large volumes of wastewater (20% or more of flow) • Requires significant power input • Requires use of anti-scalants, anti-biological agents to maintain membranes • Disposal of spent chemicals may require special handling • Depending upon specific ion-removal ratios, may actually increase SAR	$1.29 - $1.71

TABLE 5.1 (cont'd)
SUMMARY OF WATER MANAGEMENT ALTERNATIVES

WATER MANAGEMENT ALTERNATIVE	REQUIRES OTHER WATER MANAGEMENT ALTERNATIVES IN CONJUNCTION WITH THIS ALTERNATIVE?	BENEFITS/ADVANTAGES	DETRIMENTS/DISADVANTAGES	ESTIMATED COST/1000 GALLONS TO IMPLEMENT
Water Treatment Using Ion Exchange	No	• Produces very high quality water • May be ion-selective (e.g., sodium) • Allows use of produced water for anything from drinking to industrial use • Treatment units can be purchased in package plants, from very small to very large • Can be operated seasonally if necessary • Relatively small portable unit(s) may be configured for use at multiple sites • Flexibility with medium-sized units to be used at a site for several years, then moved to new site • Requires little energy/power input • Requires little operator attention, possible lengthy unattended operation • If applied properly, generates relatively small wastewater volume.	• Relatively high capital and operating cost • Loses efficiency with higher TDS water • Requires significant chemical input • Disposal of spent chemicals may require special handling • Ion selectivity to remove only sodium may be limited, thus deionization may be required • May be subject to iron fouling and require iron pre-treatment	$1.85 - $2.37
Water Treatment Using Ion Ratio Modification	Yes	• Simple system for addition of Ca and Mg • Results in a water suitable for irrigation • Very low capital cost compared to other treatments • Moderate operating cost compared to other treatments • Low energy use • Low land disturbance • Good process control with some systems • Unattended operation/infrequent maintenance	• Will increase the water EC • Based upon most water quality samples analyzed to date in the Three Horses drainage basins, this method of water treatment will prove unsuitable • Requires regular maintenance of chemical feed systems • May encounter future opposition due to salt loading potential issues • May require more detailed examination of specific salt effects on irrigable soils downstream (i.e.; effect of magnesium sulfate or magnesium chloride)	$0.14 - $0.21
Piping Water to Powder River and Constructing Water Treatment Facilities	No	• Elimination of discharges onto lands within the watershed • Elimination of holding ponds and reservoirs • Only temporary disturbance to downstream landowners (vs. perpetual disturbance if surface water discharges are allowed) • Possibility of hydropower at confluence of Dead Horse Creek and Powder River • Water treatment could be curtailed or eliminated during periods of high flows in the Powder River, which often occur in the spring or after significant precipitation events.	• Requires tremendous cooperation among CBM operators and operating entity to implement • Length of time that system would operate difficult to predict • Disposal of brine material somewhat uncertain at this time • No assurance that Montana will accept water with similar historical quality but with higher quantity than that which it has historically seen in the Powder River at Moorhead • Temporary disturbance to lands due to additional pipeline construction	$1.33
Lake DeSmet Storage Releases	Yes	• Provides relatively simple means of improving water quality of Powder River into Montana • Instream flow available during certain periods in Clear Creek, possibly improving fisheries and aesthetics	• Very limited supply only • No assurance that Montana will accept water with similar historical quality but with higher quantity than that which it has historically seen in the Powder River at Moorhead • Lake DeSmet recreational users may oppose annual drawdowns for this purpose • May require collection system of CBM water within Three Horses drainage areas, or acquiescence of landowners within the drainage areas to allow flows through their property	$0.61
Dust Abatement	Yes	• Low initial capital cost • Beneficial use of water • Can aid in mitigating CBM impacts by controlling dust • May not be enough public roads to which the water could be applied	• Limited time throughout the year that this alternative can be implemented (245 days/year) • Some question as to how effective dust abatement can be with continued application of CBM water • Possibility of making roads "greasy" • Extensive number of trucks required to dispose of all of the water	$4.00
Land Application Using Center Pivot Sprinkler Systems	Yes	• Can be very efficient, and are the least labor-intensive sprinkler application equipment • Can work with relatively low pressure • Are designed to be very uniform in application and are the best sprinkler unit to insure that leaching of salts occurs through the root zone • Once installed, center pivots require relatively little labor to operate and maintain	• Process is seasonal, thus off-season storage is required • Relatively flat terrain (generally slopes less than 6% to control runoff) is required to operate • Are significantly more expensive than other sprinkler equipment • Limited area available for large center pivots • Large power requirements required in remote areas	$0.63
Land Application Using Big Gun Sprinkler Systems	Yes	• Are capable of spreading water over large areas • Can be placed in land application areas that will not accommodate pivots • Capital costs typically much less than for center pivots	• Process is seasonal, thus off-season storage is required • Much less efficient that center pivot in terms of application to soils • Resulting evaporation may result in the concentration of salts and sodium on the soil • Wind will significantly alter the application pattern of big gun systems • Are much more difficult to achieve uniform leaching of salts through the root zone • Are more labor intensive than center pivot systems	$1.03
Land Application Using Hand Move Irrigation Pipe	Yes	• Can be used in steep terrain • Application rates can be adjusted so that the systems only require moving periodically	• Process is seasonal, thus off-season storage is required • Application efficiency is much lower than for center pivots but slightly higher than for big gun systems • Very labor intensive, requiring two operators to move the pipe	$1.14

well; the current average production is 5 gpm, and is expected to continue to decrease with time as wells "mature". (Likwartz 2002)

- In order to implement basinwide solutions, the coordination and project financing mechanisms will require substantial amounts of time. The reality is that if there are other alternatives available, the delays that will be necessary to coordinate basinwide solutions will preclude CBM companies from actively participating in such plans for water management.

- It is unlikely that a private entity will step forward and implement the basinwide solutions described in the previous section. This uncertainty would likely be due to the uncertainties discussed above regarding market conditions and lack of operator involvement or interest, particularly when other solutions could be implemented. If no private entity steps forward, it will be left to the State of Wyoming or some other public entity to implement a basinwide solution. Although such implementation is possible, the concept of constructing and operating a water management solution – particularly an expensive and potentially risky one - for the benefit of private enterprise will require lengthy debate and ultimate legislative approval. The time factor associated with such debate and approval will again prove detrimental to advancing forward with such a plan.

B. In lieu of the development of basinwide solutions, we instead recommend that site-specific solutions be pursued, recognizing that there is no "one-size-fits-all" solution for the problems associated with CBM water management within the Three Horses watersheds. A range of water management alternatives, integrated on a case-by-case basis to meet the needs of both landowners and the CBM operators, can more successfully be pursued. Listed below are those solutions that should be evaluated and considered each time that a permit is being considered for discharge.

- **Direct Discharge** Direct discharge into receiving streams is not recommended among the range of alternatives, unless there is concurrence within the drainage basins by all affected downstream landowners, **and** the states of Wyoming and Montana reach accord on the amount of discharge – if any – that could be made into the Powder River for ultimate delivery into Montana. Some landowners may desire to have CBM waters released onto their property, as it can provide valuable stock and wildlife water on a continual basis. Others, however, may not desire to have this water discharged to their property. The continual inflow of water along the stream will change the riparian vegetation directly adjacent to the stream, converting from the grasses historically seen to wetland species. Livestock operations could be affected by an encroachment upon areas historically used for calving operations. Stream crossings could prove to be a hindrance. Areas where spreader dikes exist could have water retained on a continual basis, affecting hay production and haying operations.

  For those downstream landowners that would receive these discharges, arrangements would have to be made by CBM operators to allow for these discharges to flow through these downstream properties. From a legal standpoint, it is unclear as to if CBM operators have the right to allow their discharge water to flow downstream and therefore "trespass" upon the downstream user without the permission of the receiving landowner, even if the water quality is acceptable.

  To address the concerns of downstream landowners, it may be possible to construct diversion facilities that would convey water around the spreader dike dams and channelize water (via ditch and pipeline construction) to avoid water spreading out in braided areas. Arrangements would have to be made, and facilities constructed accordingly, so that historical runoff events which have served as valuable irrigation sources would still be captured by the landowners.

Experience to date within the WHCW has shown that direct discharge can be utilized without the CBM water ultimately reaching the Powder River. Releases are currently being made that are not ultimately making their way to the river. This may be due in part to the amount of water that can infiltrate into shallow aquifers being higher than originally predicted. Such an increase in infiltration quantities has occurred elsewhere. Representatives of the BLM have recently stated that the amount of water being lost due to infiltration in the Belle Fourche basin is approximately 80-90%. This percentage compares to original estimates of 2%. (Meyer 2002) The U.S. Department of Interior BLM's 2002 Draft Environmental Impact Statement for the PRB on Coal Bed Methane also assumed that 80 percent of the total volume of CBM produced water would be lost via conveyance, of which 82 percent of the conveyance loss would be due to infiltration and 18 percent due to evapotranspiration. These values were derived from studies of surface water losses in creek flows within several drainages of the PRB. (U.S. Department of the Interior BLM 2002, Meyer 2000, Applied Hydrology Associates 2001).

Although surface gradients within the Three Horses watersheds are generally steeper than those in the Belle Fourche basin, and soil characteristics may be somewhat different, there is evidence that similar infiltration is occurring within the Three Horses areas. The collection of measurements at the BLM's gaging station just upstream of the confluence of Dead Horse Creek with the Powder River (operated by the USGS) has been discontinued due to the lack of flow (less than one cfs) since its reinstallation in 2001, with the exception of precipitation events. Similar data shows essentially no flow at the BLM's Wild Horse Creek gaging station near the confluence with the Powder River. No flow currently exists within Spotted Horse Creek despite upstream CBM development and releases.

It is noteworthy that Belle Fourche River streamflow rates have changed little since the commencement of discharge of CBM water into receiving streams. Figure 5.1 portrays data on flows in the Belle Fourche drainage over the last several years. Despite direct discharge of CBM water (vs. using containment facilities prior to discharge), the data suggests that the actual amount of water flowing in the mainstream has had essentially no effect on total streamflows. (George 2002)

If the likelihood exists that CBM water will find its way to the Powder River (such as being in close proximity to the confluence), direct discharge should not be considered as a water management solution until Wyoming and Montana reach accord. Furthermore, if there is the possibility that CBM flows will reach downstream lands whose owners have not concurred with such releases, direct discharge should not utilized.

- **Containment-and-Loss Reservoirs** Containment-and-loss reservoirs, particularly those that are not constructed on-channel, have been shown and should continue to be an effective means of managing water within the Three Horses basins. As discussed above, infiltration rates potentially being higher than originally estimated and decreasing CBM flows with time may allow containment-and-loss facilities to provide a means to manage all water collected from CBM activities without requiring direct discharge.

On-channel facilities offer the advantage of being available for use for stock water retention after CBM activities have been completed. Off-channel containment facilities, however, can likely address potential concerns of downstream landowners that would otherwise pose problems with the on-channel structures. If constructed on-stream, water rights factors can become issues, as CBM storage facilities with unused capacity store waters during runoff events that have historically flowed downstream and irrigated lands. Outlet works on these on-stream facilities can be of little or no benefit, as the water released is CBM water vs. natural runoff.

On-channel facilities can be constructed to bypass all flows not related to CBM discharges. Constructing such facilities, however, can prove to be expensive and perhaps cost-prohibitive. As such, off-channel facilities usually are a better choice for impoundment of the CBM water to allow for infiltration and evaporation.

Containment facilities can offer the additional advantage of providing additional wildlife habitat. Ducks, geese and numerous animal species have found CBM ponds to be attractive locations, and there is no evidence to date that there are consequences with their use of these ponds. (Ramirez 2002) However, the potential exists that CBM water seeping into the ground may ultimately find and follow an impermeable layer that eventually outcrops at the surface.

As discussed previously, containment-and-loss facilities should be constructed so that infiltrating water does not ultimately find its way to the surface nor impact existing groundwater uses.

- **Containment-and-Release Reservoirs** This water management alternative can be potentially employed if there is concurrence by downstream landowners within each drainage, if release occurs in conjunction with major runoff events that would serve to dilute the stored CBM water. If the release occurs during the non-irrigation season, not only would there be the need to obtain downstream landowner concurrence, it is likely that similar concurrence would have to be received by the State of Montana. Assuming that releases are performed that would not prove detrimental to irrigators in Montana (due to the time of year or amount of water within the Powder River that releases occur), it is possible that Montana would provide such concurrence.

  An important factor in utilizing this water management alternative would be the sizing of facilities, if the plan is to release waters in conjunction with major runoff events. If the major runoff events do not occur, there is the risk that the capacity of the storage facilities will be exceeded.

- **Injection** Although very site-specific and not feasible for use in many areas of the Three Horses watersheds, this water management alternative offers perhaps the greatest overall benefit to the State of Wyoming. By injecting this water back into the ground, water that would otherwise be lost to downstream states can be restored in aquifers and made available for future use in Wyoming. However, as shown in the cost comparisons, injection can be a very expensive alternative for CBM operators, and unless receiving aquifers meet certain characteristics, economics will not allow for this alternative to be used. Most operators view the injection facilities as a complement to existing water management techniques rather than as a primary, stand-alone method of managing water.

  Shallow aquifers (e.g., Wasatch, Fort Union, Lance or Fox Hills) are more likely to allow future recovery of injected water without water quality issues and large expenses.

However, injection into shallow aquifers must be performed in a manner to prevent outcropping of injected waters. As discussed, several shallow injection wells have been permitted and operated in the WHCW. These wells have been completed in the Felix Coal. Opportunities for injection into this coal seam, however, may be examples of the limitations imposed due to formation outcroppings in the lower portions of the WHCW valley. Similarly, the Smith Coal, although seeing more intensive CBM development, may provide an additional suitable receiving aquifer if gas production is not apparent. WO&GCC data indicates injection wells have also been completed in the deeper Wall/Pawnee coal formations within the WHCW.

The potential also exists that depleted oil-and-gas aquifers may offer promise as targets for injection. Areas within the Three Horses drainage areas that offer such promise include the following:

- DHCW: Historical withdrawals from the Muddy, Sussex and Shannon sands warrant further investigation. These zones have been used previously via injection to provide for water flood or secondary recovery purposes.
- WHCW: The potential exists that significant depletion of the Muddy Sandstone may have occurred due to the presence of small oil and gas production. There may be site-specific aquifers as a result of these withdrawals that provides opportunities for injection.

- **<u>Enhanced Evaporation Using Atomizers and Misters</u>** These two techniques offer the advantage of dissipating CBM water through evaporation, thereby acting as another alternative for water management. Like many other alternatives, however, these techniques must be used in conjunction with others, primarily due to seasonal variations in the ability to evaporate water. Storage of CBM water during the months when evaporative losses are not high becomes an integral part of the decisions to select these water management alternatives.

  In those areas where atomizers or misters are used that water is not evaporated and falls to the ground, soil quality management techniques very similar to land application must be adhered to. Otherwise, those problems that result from land application of waters containing higher concentrations of EC and SAR will similarly result. Sites must also be chosen that do not allow the water that is not evaporated to travel overland and into downstream channels.

- **<u>Water Treatment</u>** Water treatment alternatives were focused on water treatment to produce water suitable for direct discharge or land application, or in conjunction with other alternatives to maximize the beneficial use of the water and/or meet discharge criteria. The three treatment techniques examined: 1) reverse osmosis, 2) ion exchange, and 3) ion ratio modification, require active operations of treatment facilities. Reverse osmosis is severely limited by costs and logistical considerations. A single stage RO unit outputs 40% of the input water as a waste byproduct that is essentially more problematic in many respects than the raw water input. On a large scale, the quantity of concentrate becomes unmanageable. A two-stage RO system produces 20% of the input water quantity as wastewater: still quite high and, at a large scale, very difficult to manage. The water from RO must be pre-processed (filtered) to remove suspended solids, and the water must be free of the potential to form precipitates on the membranes such as iron and manganese precipitates. The energy and maintenance requirements for RO technology are considerable. At this time, reverse osmosis cannot be recommended as a viable water management technique.

Ion exchange has serious technical limitations. Ion exchange media that is ion selective, particularly of sodium, are not particularly selective and suffers from excessive loading at high TDS. At this time, there appears to be no known exchange resin or material that is ion-specific for sodium. Exchange processes generate a waste byproduct during media regeneration of high concentration that must be disposed. The cost of ion exchange, as a result of and in addition to technical limitations, exceeds reverse osmosis. Ion exchange requires pre-processing (filtration) of the water to remove suspended solids and removal of constituents that may precipitate and foul exchange media (e.g., iron). Ion exchange cannot be recommended as a viable management alternative.

Ion ratio modification essentially is an adjustment of the SAR through addition of calcium or magnesium salts to shift the ratio of sodium to these cations and bring the SAR to within acceptable limits. The net effect, however, is to increase the EC. There are a number of methods to implement this treatment technology, which is, in fact, more of a water **conditioning** technology. For those CBM waters that are well within agricultural limits or discharge limits for EC, this technology has excellent potential. It is relatively simple and inexpensive, and when properly applied to the right waters, it may be useful as an associate technology to land application.

- **Dust Abatement** Dust abatement is another water management alternative that, when employed in conjunction with other alternatives, offers promise as a means of water disposal and, to some extent, a beneficial use. Seasonal use, water quantities, and area-specific costs preclude this alternative from offering a total solution. As with other several other alternatives being considered, dust abatement also offers a means to provide for a beneficial use of this water that would otherwise be lost to the citizens of Wyoming.

- **Land Application** A water management alternative with significant potential, if properly employed, is the use of CBM water for irrigation purposes. Based upon the water quality and soils data collected, land application may be very site-specific, and chemical amendments to the soil will likely be required. In order for land application to be successful, intensive management of the process is necessary.

  Used in conjunction with containment facilities (which retain CBM water during the non-irrigation season), this water management alternative can eliminate the need for discharge while simultaneously providing needed irrigation water. Recent efforts in the Prairie Dog Creek watershed (an area in which CBM water quality is generally poorer than that within the PRB) have shown that CBM water may be applied to existing soils, where marginal success has occurred to date. Long-term success in this area, however, has not yet been shown, and success can be reached only as long as the locations selected have acceptable soil conditions and topography, and that the necessary chemical amendments are employed. As a result, considerable discussion within this study has centered upon procedures that can be employed to evaluate this potentially very beneficial water management alternative.

  The previous discussions on this water management alternative have provided information on the methods and locations where land application can be employed. In particular, the SHCW soils appear to offer the largest areas where land application can be best employed.

  It should be recognized that this study provides only general guidance on the use of this water management alternative within the Three Horses drainage areas. If a landowner does indeed desire to work with CBM companies in order to pursue this method, more intensive studies should be performed on the site-specific areas proposed for use by a trained soils scientist. It may be worthwhile for CBM companies to offer to fund independent, site-specific reviews for landowners with prospective lands which can be used for this alternative.

Land application techniques discussed have included the use of center pivot sprinklers, big gun sprinklers, or hand move pipe.

6. PROJECT FINANCING PLAN

The recommended water management alternative for the Three Horses watershed areas included an integrated approach for managing CBM water. This integrated approach assumes that all costs for managing CBM water will be the responsibility of the operators. This approach is consistent with current CBM development within the Three Horses drainages; i.e., there is no direct public financing involved in water management techniques, nor is any planned. As such, there will be no need for development of public entities that can utilize statutory mechanisms to provide for lower cost public financing.

Assuming, however, that an approach different than the recommended integrated approach is ultimately pursued, there may be opportunities for public involvement. For instance, should it be decided that a water management alternative such as collecting all CBM water and treating it for discharge into the Powder River is pursued, the scale of the project and need for considerable up-front financing and participation by all CBM stakeholders would likely benefit from public participation and financing. The State of Wyoming and/or the federal government may decide that it is in their best interests to participate in the costs to implement the selected water management alternative. Should this be the case, funding programs within the State and federal government could conceivably assist in the public financing. Such assistance will require the formation of a public entity to proceed forward with a publicly-financed, basinwide plan.

The funding sources and public entities possible are discussed below.

6.1 Potential Funding Sources

6.1.1 WWDC

This state agency provides grants and loans to be utilized for the development of water within the State of Wyoming. Funding for the WWDC originates from a tax placed upon extracted minerals, including principally coal. Eligible projects include those associated with the development and transmission of water, but not the treatment or distribution of water. A case might be made, however, that implementation of a plan that would maximize development of CBM in the state without jeopardizing the state's environment would qualify for WWDC funding.

Grants are usually available for 50% of the cost for project development. Loans for the non-grant share of project-eligible costs are available at a current rate of 6% (for agricultural loans only) and terms of up to 30 years, although longer terms may also be considered.

6.1.2 Environmental Protection Agency - Section 319

The U.S. Environmental Protection Agency (EPA)'s Section 319 of the Clean Water Act program provides for design and construction funding for water quality improvement projects. The program is administered in Wyoming by WDEQ, and projects are prioritized by the Governor's non-point task force. Currently approximately $1.6-1.7 million is available annually for eligible projects, with grants available for up to 60% of project costs.

There is an emphasis in this program upon non-point projects; however, due to the protection of water quality within the Three Horses drainage basins that would be achieved by implementation of a water management alternative, it is possible that this program may assist in this implementation.

6.1.3 U.S. Department of Agriculture's 566 Program

The U.S. Department of Agriculture's (USDA) 566 program is another source of funding that might be utilized for implementation of a water management alternative that would protect water quality within the Three Horses basins. Named after Public Law 566, which authorized its original federal funding, this program can fund projects for stream bank protection, stream stabilization, and resulting benefits to water quality, wildlife, and fisheries. The program is typically utilized to offer assistance for both on-farm and off-farm improvements. Applicants compete nationwide (vs. statewide) for funding. Although typically utilized for farm programs, the Bush administration's interest in developing domestic energy sources may cast a favorable light on using these USDA funds for water quality protection within these rural areas.

Receipt of funding under the 566 program is conditioned upon successful demonstration of a benefit/cost ratio of greater than one, as determined by a feasibility study conducted by USDA staff. This study is performed at no cost to the applicant, and takes approximately six months to complete. There is an approximate two-year lag between the time of feasibility request and receipt of design and construction funding, assuming that the benefit/cost ratio makes receipt of the federal funding possible. It is typically recommended that a local sponsor, such as a public entity, apply for funding.

There is no maximum dollar allotment for a particular project, although projects requiring funding for amounts greater than $5 million require Congressional approval. There is no set match; therefore, it is possible that up to 100% of the project costs could potentially be provided via this program. However, matching these monies with other sources can make the project more attractive to federal administrators reviewing applications. Given the administration's interest in domestic energy development, both federal administrative and Congressional approval may be easier to come by with such a project than with more typically funded USDA projects.

6.1.4 Wyoming Department of Agriculture's Water Quality Grant Improvement Program

This state grant program provides grants for water quality monitoring, planning and improvements. It has received appropriations from the Wyoming Legislature in the last bienniums, for amounts of $379,000 and $197,000, respectively. Historically, county conservation districts have been recipients of these funds; however, this practice is not mandatory.

6.1.5 WDEQ State Revolving Loan Fund – Clean Water Act

The WDEQ administers the State Revolving Loan Fund (SRF) for both the federal Safe Drinking Water Act and Clean Water Act (CWA) in Wyoming. Funding for the SRF originates from Congressional-supplied monies to the EPA, which in turn allocates a portion of these funds to each state.

Loans from the SRF are available at a current rate of 4% and term of 20 years. No grant monies are available from this funding source. WDEQ continually updates a ranking of projects eligible for the SRF.

Typically, monies from this loan program are used to fund domestic water and sewer systems throughout the state. However, due to the abundance of loan monies currently available in the State's CWA SRF, it is possible that a publicly-funded project can provide for water quality improvements, such as one that would require implementation of a regional plan and unilateral participation, would be eligible for loans.

6.2 Possible Public Entity Formation

In order for any prospective funding agency to have an entity with whom it may contract, it is necessary to establish an organization for such contracting purposes. Typically, this involves establishment of a public entity. Either a watershed improvement district or joint powers board would be a logical public entity that would achieve this purpose in Wyoming.

W.S. 41-8-101 et seq. address watershed improvement districts, and W.S. 16-1-101 et seq. discuss joint powers board. Whether it be a watershed improvement district or joint powers board, a public entity such as this would appear to have the legal authority to both implement and finance a regional solution to the management of water within the Three Horses drainage basins. The public entity could apply and potentially qualify for monies from the programs that have been discussed. These funds could be matched with monies provided by private CBM operators. Alternatively, the public entity could choose to both construct and operate a regional solution using both financing provided via these programs and a one-time State appropriation authorized by the Wyoming State Legislature. Use of the regional system would be mandated by the State if a company desires to develop its CBM resources. System use would require that user fees be paid by the CBM operator to the State, with the fee established in a manner so that the State would be repaid for its costs in the development of the regional system. Alternatively, the State may consider that it in its best overall interests to develop the regional solution, and either bear the cost for its implementation or reduce the required user fee amount to a level that would make it less onerous to CBM operators.

One disadvantage in implementing such a plan may be the timing involved. In order to form the necessary public entity, attain legislative approval of the recommended plan, apply for and receive public monies from the programs discussed above, and actual implement the plan, the time involved to fully realize the plan may be unattractive to the CBM operators who would make use of the plan. It would required a commitment by CBM operators to postpone any development until the plan is fully operational, which could likely take up to five years.

7. SUMMARY AND PATH FORWARD

Summary

This study has compiled considerable information on the current status of the Three Horses watersheds. Much of the information has been obtained through prior studies and data collection from state and federal agencies seeking to allow CBM development to move forward without negatively affecting the environment. Significance of some of the data has changed over the course of the study, as regulatory mandates have changed and results from other studies have influenced the importance of portions of the data. One of the most significant pieces of data was the water quality of the CBM water being produced, which showed to be a different type of water (bicarbonate-based vs. sulfate-based) and, as a general rule, unsuitable for irrigation without the use of chemical amendments.

The data that has been collected has been used to evaluate potential CBM impacts and, based upon those impacts, evaluate a series of potential water management alternatives for the basins. Those water management alternatives include:

- Direct discharge to stream channels,
- Containment-and-loss reservoirs,
- Containment-and-release reservoirs,
- Injection,
- Enhanced evaporation (using either atomizers or misters),
- Piping water to other drainage basins,
- Piping water to the Powder River for direct discharge,
- Water treatment (utilizing reverse osmosis, ion exchange, or ion ratio modification),
- Piping water to the Powder River and constructing water treatment facilities,
- Releasing mixing water from Lake DeSmet,
- Dust abatement through use of CBM water, and
- Land application.

The evaluation of water management alternatives summarized both the advantages and disadvantages of the alternatives, as well as estimated reconnaissance level costs to implement each of them. Estimated costs, while only reconnaissance in nature and thus very approximate, were portrayed in a format so that one could compare the relative cost of each to the other alternatives being evaluated.

The evaluation of water management alternatives showed that there is no single solution that adequately addresses all of the issues surrounding water that is released as a result of CBM development. It also showed that private, individual solutions to the CBM water issues would be more cost-effective and more easily implemented than basinwide solutions that may require public funding or more direct public involvement in plan development.

The evaluation also showed that the present methods of addressing CBM water issues in the Three Horses basins; i.e.,

- direct discharge to stream channels,
- containment-and-loss reservoirs,
- containment-and-release reservoirs,
- injection,
- enhanced evaporation,
- dust abatement, and
- land application.

are the best overall solutions given the present regulatory requirements and when used in combination. When used properly and in the correct environment, these methods can offer the State of Wyoming and the individual landowner the opportunity to beneficially use this CBM-produced water.

Particular emphasis was placed in this study on the possible use of CBM water for irrigation purposes (i.e., land application) within the Three Horses basins. Given the series of drought years that have recently been experienced, an opportunity to increase forage production through the use of the temporary CBM water was believed to warrant special emphasis. Results showed that, while opportunities do in fact exist, care must be taken in selecting suitable locations, and chemical amendments to the soil to negate the effects of salinity and sodicity will likely be required. Figures and tables provided within this study can be utilized to preliminarily evaluate those areas that can make use of the water for irrigation. However, more intensive, site-specific evaluations should be conducted if irrigation with CBM water is in fact being seriously considered, and experienced soils scientists should be employed prior to embarking upon any plan to use the CBM water for irrigation purposes.

Path Forward

It would be ideal if the findings of this study identified one unique, innovative method that could successfully address the needs for effective CBM water management in the Three Horses watersheds. The findings, however, instead recommend in many ways a continuance of existing water management options; i.e., the employment of several water management alternatives by the individual CBM companies. Direct discharge to channels, containment-and-loss reservoirs, containment-and-release reservoirs, injection, enhanced evaporation using atomizers, dust abatement, and land application are all water management alternatives that are in use within the watersheds.

Due to the concerns expressed regarding basinwide solutions, it is believed that CBM water management should remain in the hands of the private sector, and that small, individual methods of water disposal continue to be utilized. As such, while the conservation districts should continue to play active roles in the monitoring and overseeing of CBM development within their various jurisdictions, their role should not be expanded to participate in publicly-funded projects that would implement basinwide solutions to water management. Conservation districts, in their current role of partnering with landowners and resource agencies in watershed planning via EPA Section 319, PL-566 watershed projects, and locally-led initiatives, already are active in publicly-funded projects. They are a logical tool to bring everyone together to plan for sound resource management decisions, including CBM development companies, resource agencies, and local landowners. .

A very important future development for the continuance of CBM activities will be the decisions reached in the negotiations between the State of Wyoming and State of Montana relating to discharges in the PRB. If decisions reached allow some discharge that exceeds historical water quality values observed along the Powder River, it will become even more imperative that the CBM companies and landowners along the Three Horses streams cooperate, as it is likely that direct discharges to channels will increase. Such direct discharges cannot be allowed to negatively impact the landowner's operations. If, on the other hand, state agreements do not allow for such discharges into the Powder River, landowners in the Three Horses areas are likely to see the other water management alternatives discussed above be used more extensively.

It is hoped that this study will provide the affected landowners with a better understanding of the drainage areas within which they live as they relate to CBM development, the costs and alternatives inherent in CBM development, the issues faced by both states as they negotiate agreements, and the potential opportunities that they may have to make beneficial use of this water that will likely continue to affect their watersheds. Only through this better understanding of the issues surrounding CBM development will all parties involved, including landowners, operators and regulators, be able to reach the critical agreements necessary that will be required to develop this energy resource so important to our country.

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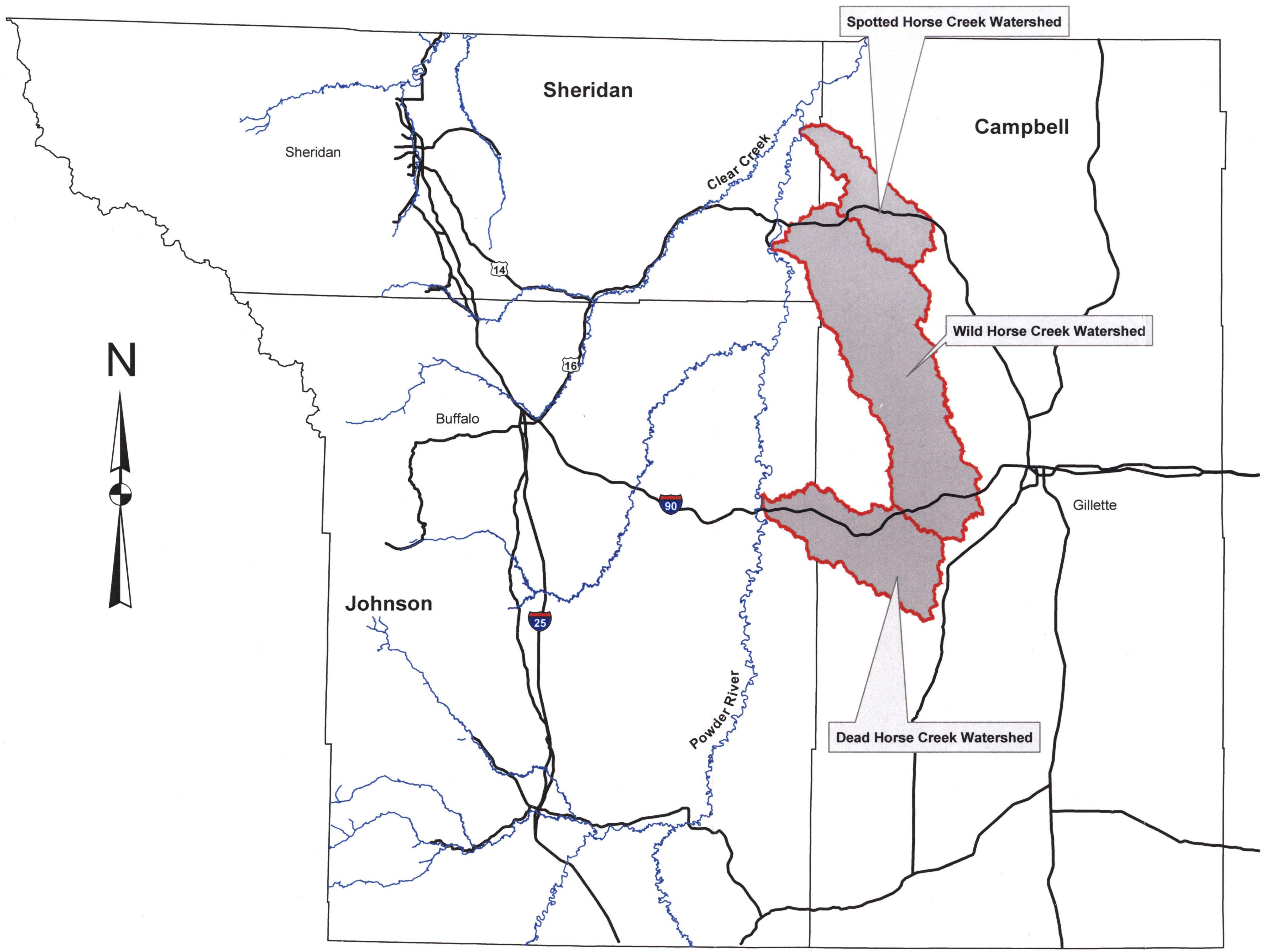
FIGURES



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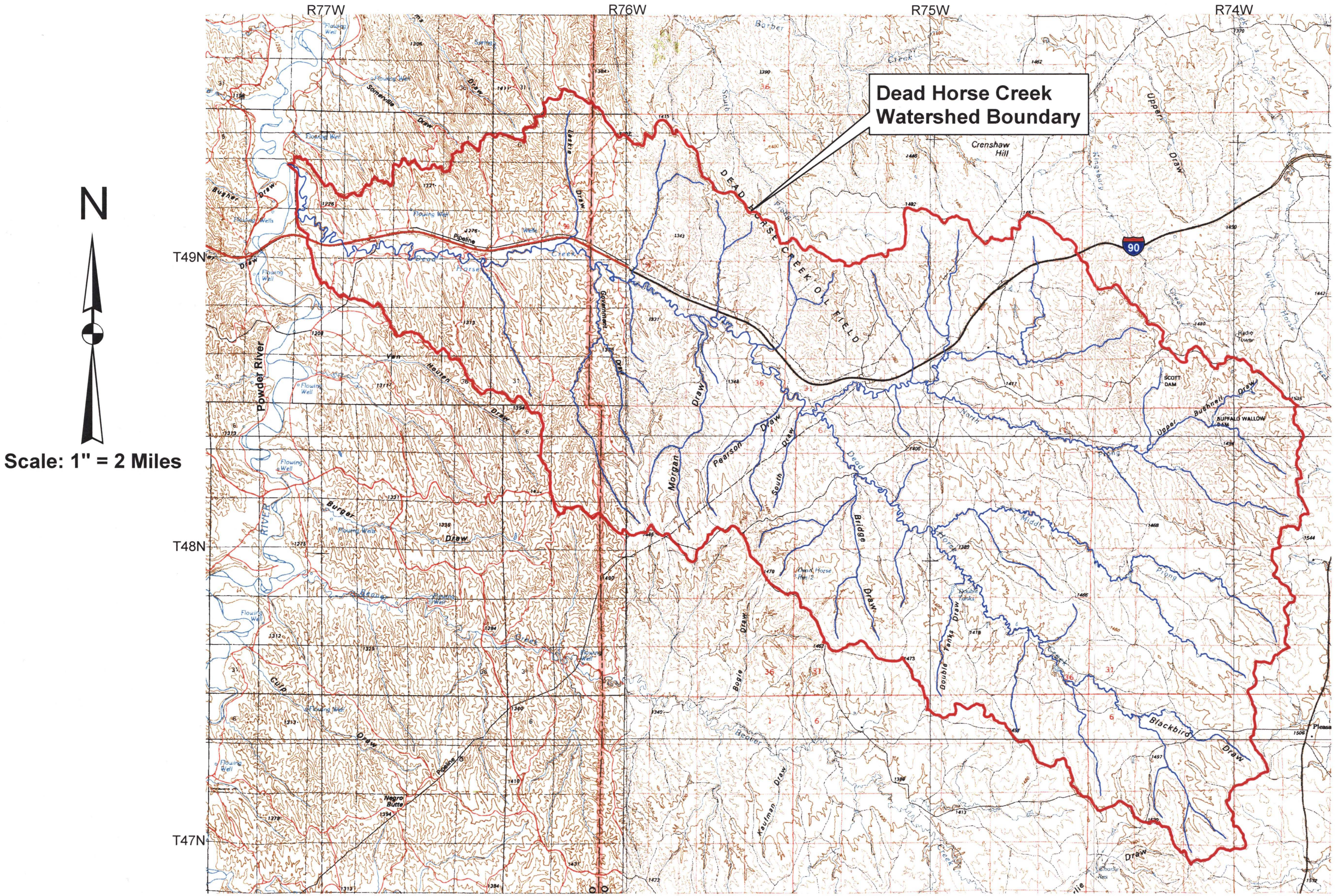
LOCATION MAP

THREE HORSES WATERSHED PLAN LEVEL I STUDY

EnTech, Inc.
Consulting Engineers
Transportation - Municipal - Environmental - Water Resources

1949 Sugarland Drive, Suite 205
Sheridan, Wyoming 82801
Phone 307-673-1542
Fax 307-673-1547
E-mail entech@entechusa.net

FIG. 2.1



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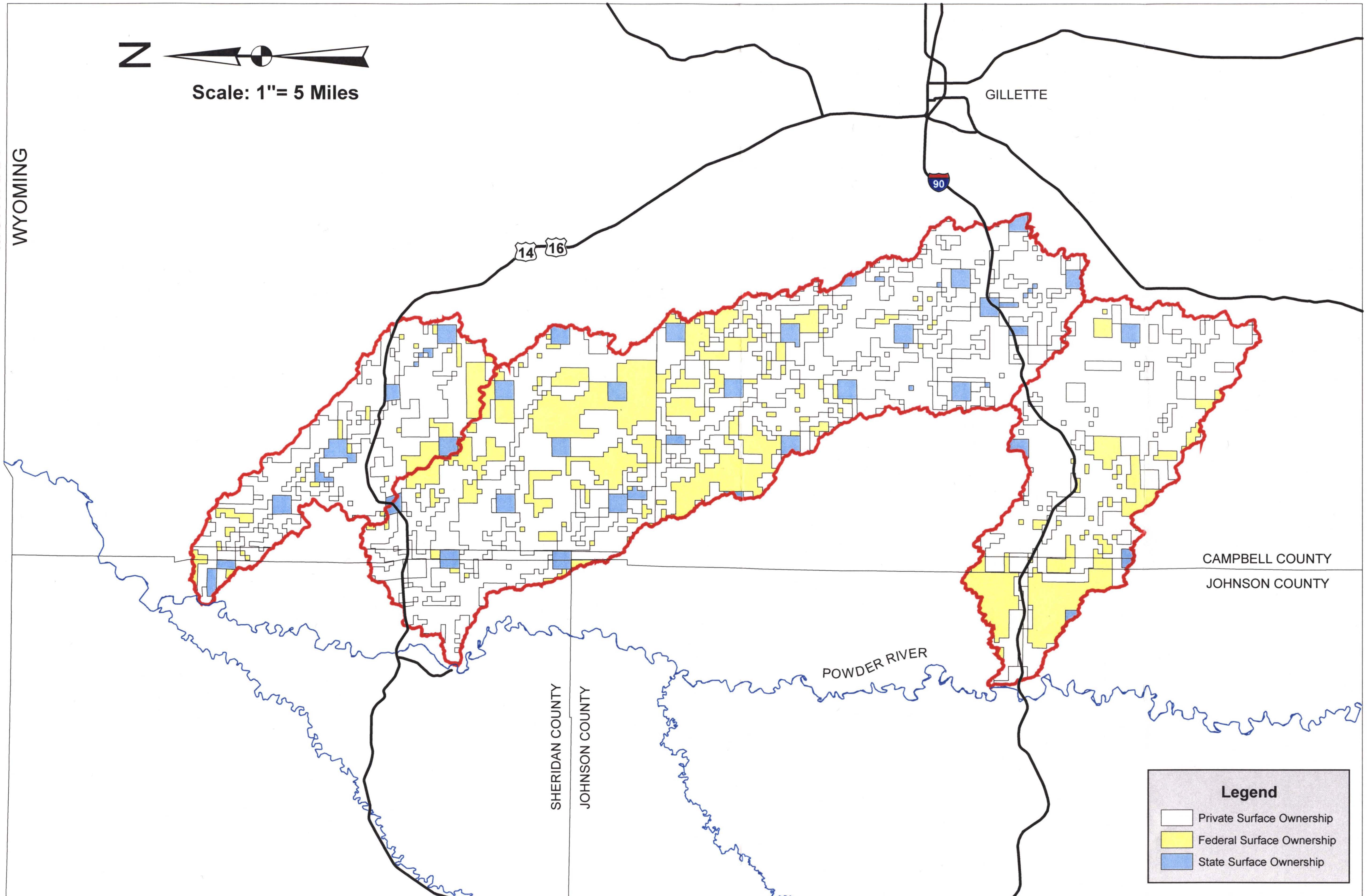
DEAD HORSE CREEK WATERSHED BOUNDARY

THREE HORSES WATERSHED PLAN LEVEL I STUDY

EnTech, Inc.
Consulting Engineers
Transportation - Municipal - Environmental - Water Resources
1949 Sugarland Drive, Suite 205
Sheridan, Wyoming 82801
Phone 307-673-1542
Fax 307-673-1547
E-mail entech@entechusa.net

FIG. 2.1.1



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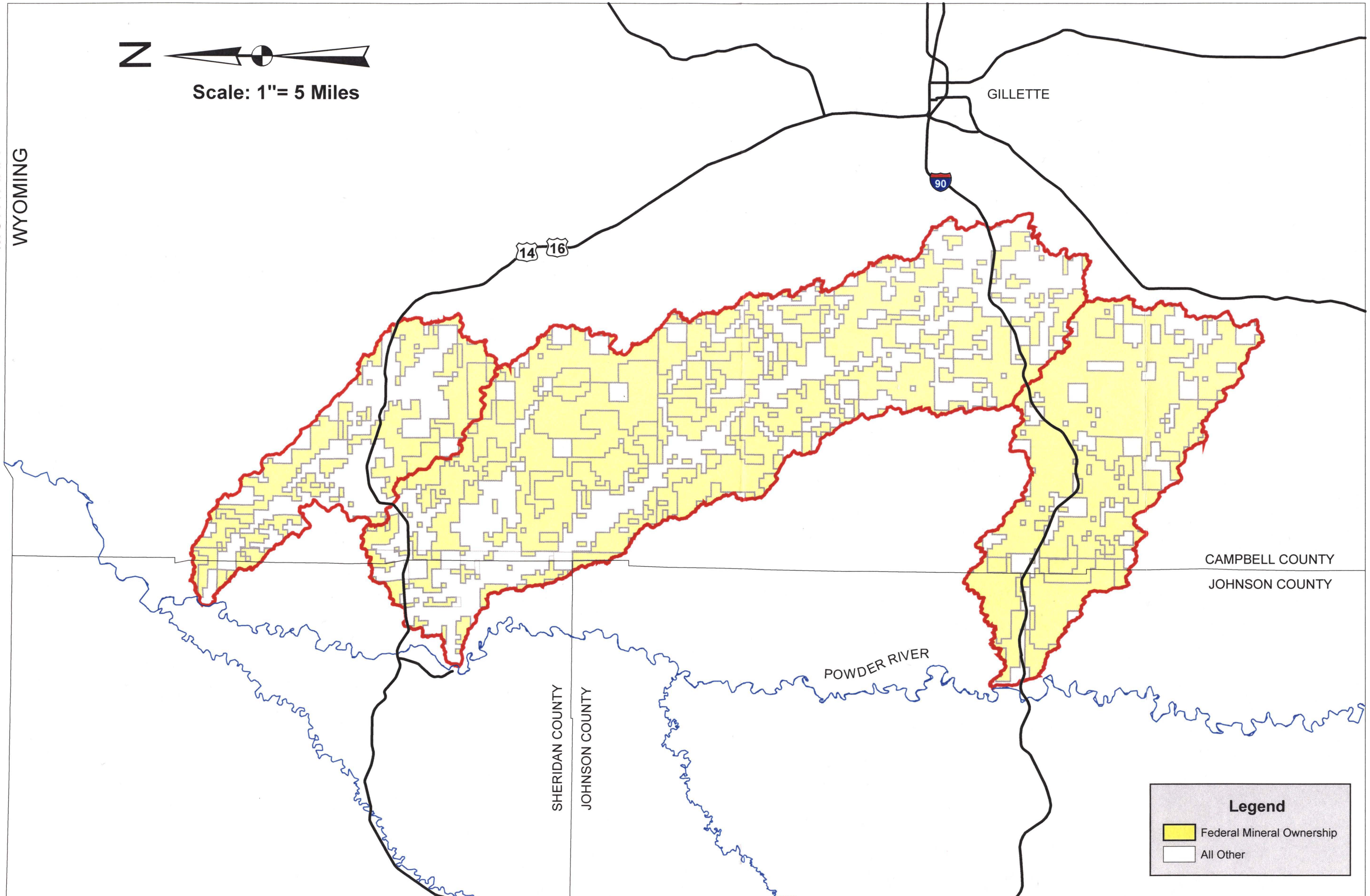
THREE HORSES WATERSHEDS SURFACE OWNERSHIP

THREE HORSES WATERSHED PLAN LEVEL I STUDY

EnTech, Inc.
Consulting Engineers
Transportation - Municipal - Environmental - Water Resources
1949 Sugarland Drive, Suite 205
Sheridan, Wyoming 82801
Phone 307-673-1542
Fax 307-673-1547
E-mail entech@entechusa.net

FIG. 2.1.2



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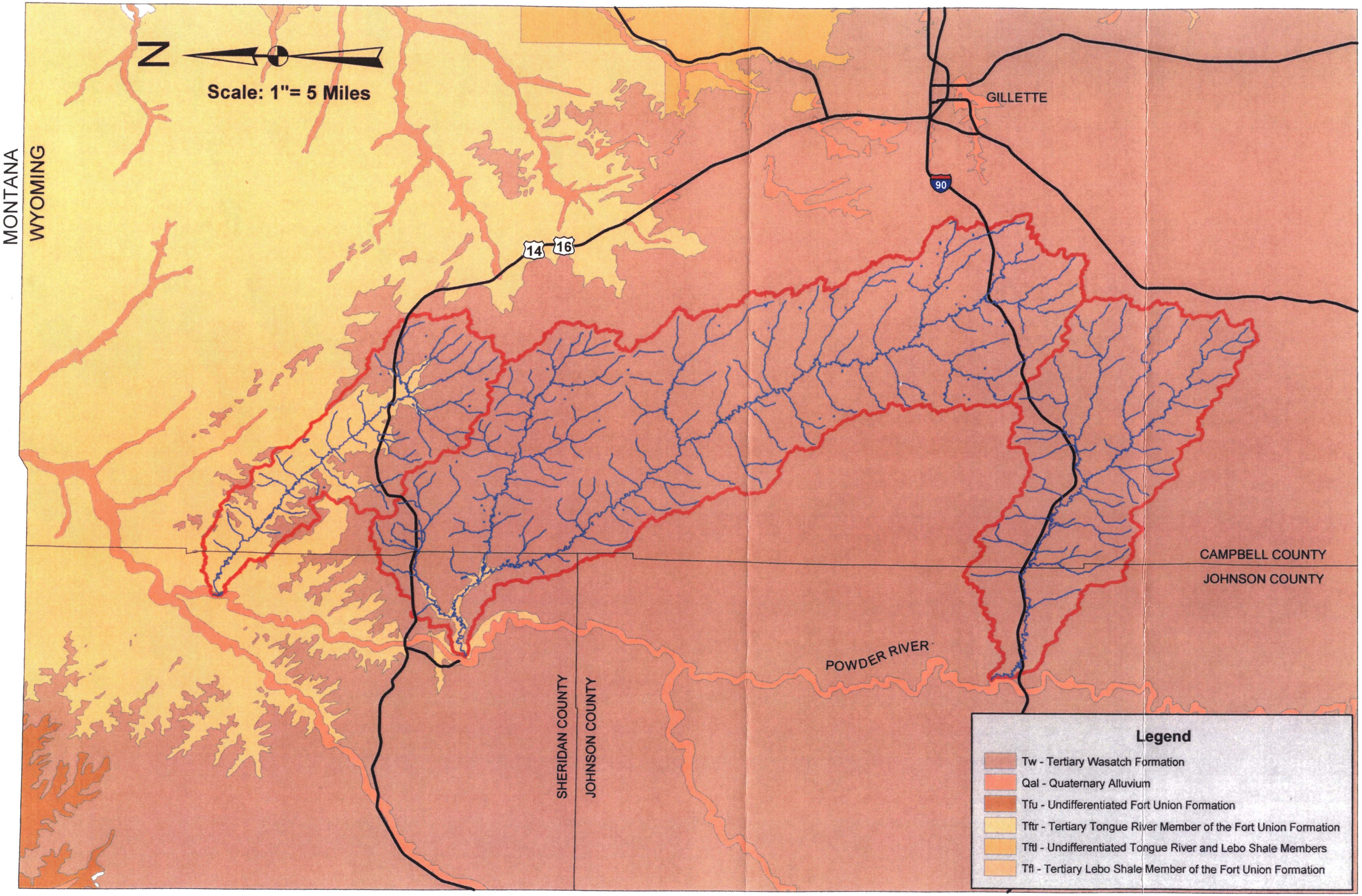
THREE HORSES WATERSHEDS
MINERAL OWNERSHIP

THREE HORSES
WATERSHED PLAN
LEVEL I STUDY

EnTech, Inc.
Consulting Engineers
Transportation - Municipal - Environmental - Water Resources
1949 Sugarland Drive, Suite 205
Sheridan, Wyoming 82801
Phone 307-673-1542
Fax 307-673-1547
E-mail entech@entechusa.net

FIG. 2.1.3



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THREE HORSES WATERSHEDS
SURFACE GEOLOGY

THREE HORSES
WATERSHED PLAN
LEVEL I STUDY

EnTech, Inc.
Consulting Engineers
Transportation - Municipal - Environmental - Water Resources
1949 Sugarland Drive, Suite 205
Sheridan, Wyoming 82801
Phone 307-673-1542
Fax 307-673-1547
E-mail entech@entechusa.net

FIG. 2.1.4

PERIOD	EPOCH	MA	FORMATION AND MEMBER NAME	
QUATERNARY	N/A		UNDIFFERENTIATED ALLUVIUM/COLLUVIUM	
		2.5		
TERTIARY(PART)	OLIGOCENE		WHITE RIVER FORMATION (NOT SEEN IN DHC DRAINAGE)	
		34		
	EOCENE		WASATCH FORMATION	
		57		
	PALEOCENE		FORT UNION FORMATION	TONGUE RIVER MEMBER
				LEBO MEMBER
				TULLOCK MEMBER
		66.5		
CRETACEOUS(PART)	LATE		LANCE FORMATION	
		69.5		
			FOX HILLS SANDSTONE	
		71?		
			PIERRE SHALE	

EnTech, Inc.
Consulting Engineers
Transportation·Municipal·Environmental·Water Resources
1949 Sugarland Drive, Suite 205
Sheridan, Wyoming 82801
Phone 307-673-1542
Fax 307-673-1547
E-mail entech@entechusa.net

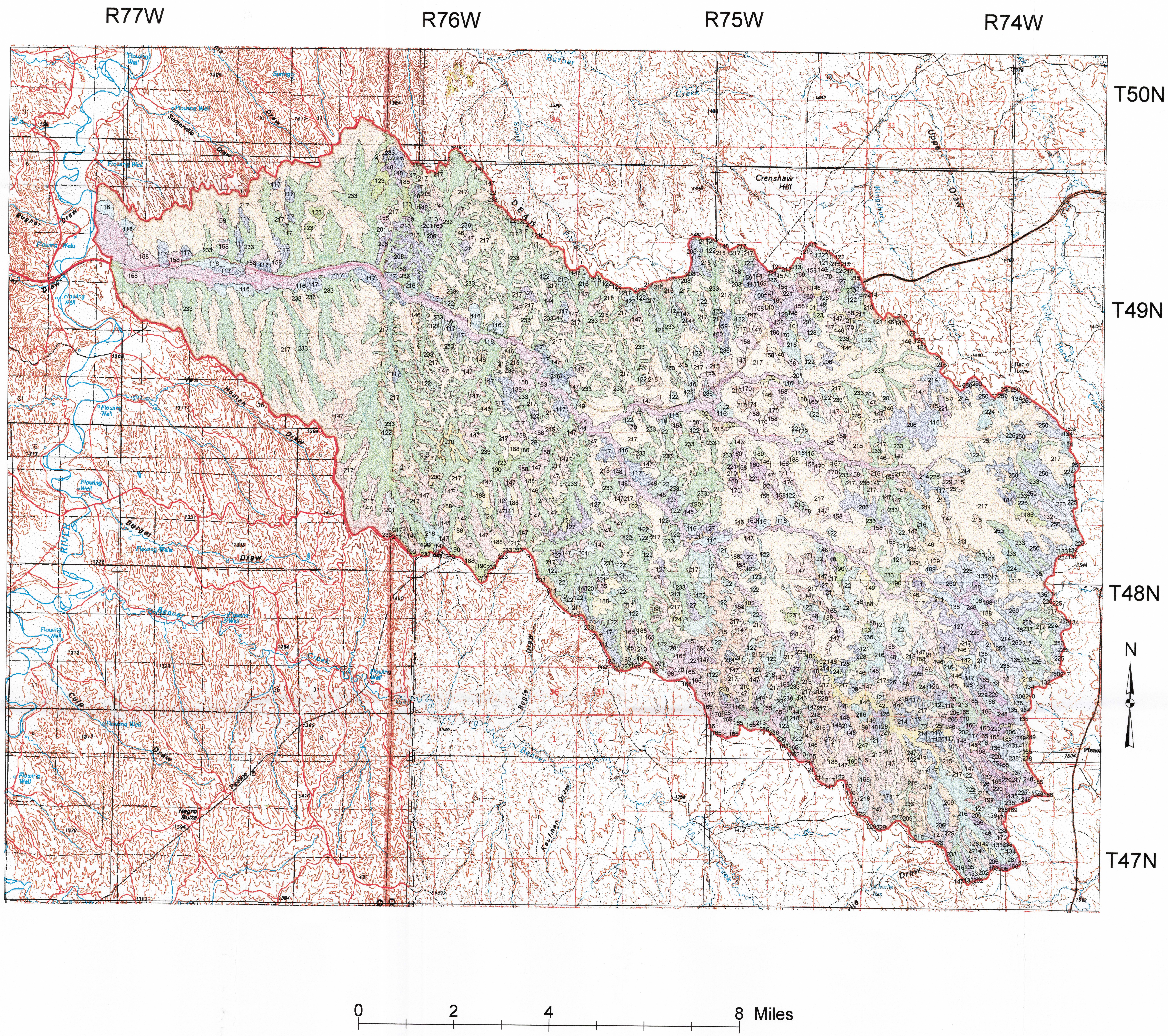
STRATIGRAPHIC NOMENCLATURE FOR THE POWDER RIVER BASIN

(AFTER, SEELAND 1992)

FIG. 2.1.5

Dead Horse Creek Watershed
Soil and Range Site Map Legend

Map Symbol	Soil - Range Site Name
101	Arvada, thick surface very fine sandy loam, 0 to 6 percent slopes – Loamy 10-14" np
102	Arvada, thick surface-Arvada-Slickspots complex, 0 to 6 percent slopes – Loamy/Saline Upland 10-14" np
103	Arwite sandy loam, 0 to 6 percent slopes – Sandy 15-17" np
106	Arwite-Elwop sandy loams, 6 to 15 percent slopes – Sandy 15-17" np
109	Bidman loam, 0 to 6 percent slopes – Loamy 10-14" np
110	Bidman loam, loamy substratum, 0 to 6 percent slopes – Loamy 10-14" np
111	Bidman-Parmleed loams, 0 to 6 percent slopes – Loamy 10-14" np
112	Bidman-Parmleed loams, 6 to 15 percent slopes – Loamy 10-14" np
114	Bowbac-Taluce-Badlands complex, 3 to 20 percent slopes –Sandy 10-14" np
116	Cambria-Kishona-Zigweid loams, 0 to 6 percent slopes – Loamy 10-14" np
117	Cambria-Kishona-Zigweid loams, 6 to 15 percent slopes –Loamy 10-14" np
121	Cushman-Cambria loams, 0 to 6 percent slopes – Loamy 10-14" np
122	Cushman-Cambria loams, 6 to 15 percent slopes – Loamy 10-14" np
124	Cushman-Shingle loams, 6 to 15 percent slopes – Loamy 10-14" np
126	Cushman-theedle loams, 0 to 6 percent slopes – Loamy 10-14" np
127	Cushman-Theedle loams, 6 to 15 percent slopes – Loamy 10-14" np
128	Cushman-Worf loams, 3 to 15 percent slopes – Loamy/Shallow Loamy 10-14" np
129	Delconey-Hiland sandy loams, 0 to 6 percent slopes – Sandy 10-14" np
130	Delconey-Hiland sandy loams, 6 to 15 percent slopes –Loamy 15-17" np
131	Deekay loam, 0 to 6 percent slopes –Loamy 15-17" np
132	Deekay-Moorhead loams, 0 to 6 percent slopes – Loamy 15-17" np
133	Deekay-Moorhead loams, 6 to 15 percent slopes – Loamy 15-17" np
134	Deekay-Oldwolf loams, 0 to 6 percent slopes – Loamy 15-17" np
135	Deekay-Oldwolf loams, 6 to 15 percent slopes – Laomy 15-17" np
136	Deekay-Ziggy loams, 0 to 6 percent slopes – Loamy 15-17" np
139	Embry-Orpha complex, 3 to 15 percent slopes – Sandy 10-14" np
142	Emigha, sodic-Arvada, thick surface complex, 0 to 4 percent slopes – Saline Upland/Loamy 10-14" np
143	Felix clay, ponded, 0 to 2 percent slopes – Clayey Overflow 15-17" np
144	Forkwood loam, 0 to 6 percent slopes – Loamy 10-14" np
145	Forkwood-Cambria loams, 0 to 6 percent slopes – Loamy 10-14" np
146	Forkwood-Cushman loams, o to 6 percent slopes – Loamy 10-14" np
147	Forkwood-Cushman loams, 6 to 15 percent slopes – Loamy 10-14" np
148	Forkwood-Ulm loams, 0 to 6 percent slopes – Loamy 10-14" np
149	Forkwood-Ulm loams, 6 to 15 percent slopes – Loamy 10-14" np
153	Haverdad-Kishona association, 0 to 6 percent slopes – Lowland 10-14" np
157	Hiland-Bowbac sandy loams, 0 to 6 percent slopes – Sandy 10-14" np
158	Hiland-Bowbac sandy loams, 6 to 15 percent slopes – Sandy 10-14" np
159	Hiland-Vonalee sandy loams, 0 to 6 percent slopes - Sandy 10-14" np
160	Hiland-Vonalee sandy loams, 6 to 15 percent slopes – Sandy 10-14" np
164	Lismas-Sabatka-Badlands complex, 3 to 45 percent slopes – Shallow Clayey/Dense Clay 10-14" np
165	Jayem sandy loam, 6 to 20 percent slopes – Sandy/Loamy 15-17" np
166	Jaywest loam, 0 to 6 percent slopes – Loamy 15-17" np
168	Jaywest-Spottedhorse loams, 0 to 6 percent slopes – Loamy 15-17" np
169	Julesburg sandy loam, 0 to 6 percent slopes – Sandy 15-17" np
170	Keeline-Tullock loamy sands, 6 to 30 percent slopes – Sandy 10-14" np
171	Keeline-Tullock-Niobrara, dry, complex, 3 to 30 percent slopes – Sandy/Shallow Sandy 10-14" np
172	Keyner fine sandy loam, 0 to 6 percent slopes – Loamy 10-14" np
180	Maysdorf-Pugsley sandy loams, 6 to 15 percent slopes – Sandy 10-14" np
183	Moorhead-Leiter clay loams, 0 to 6 percent slopes – Clayey 15-17" np
184	Moorhead-Leiter clay loams, 6 to 15 percent slopes – Clayey 15-17" np
185	Moskee fine sandy loam, 0 to 6 percent slopes – Sandy 15-17" np
188	Orpha-Tullock loamy sands, 6 to 30 percent slopes – Sandy 10-14" np
190	Parmleed-Renohill complex, 3 to 15 percent slopes - Loamy 10-14" np
198	Recluse loam, 0 to 6 percent slopes – Loamy 15-17" np
199	Renohill-Savageton clay loams, 0 to 6 percent slopes – Clayey 10-14" np
200	Renohill-Savageton clay loams, 6 to 15 percent slopes – Clayey 10-14" np
201	Renohill-Shingle-Worf complex, 3 to 15 percent slopes – Clayey/Shallow Loamy 10-14" np
202	Renohill-Worfka clay loams, 3 to 15 percent slopes – Clayey/Shallow Loamy 10-14" np
205	Samday-Savageton clay loams, 3 to 15 percent slopes – Clayey/Shallow Clayey 10-14" np
206	Samday-Shingle-Badlands complex, 10 to 45 percent slopes – Shallow Clayey/Shallow Loamy 10-14" np
207	Cromack-Fairburn-Ucross complex, 3 to 20 percent slopes – Clayey/Loamy 15-17" np
208	Savageton-Silhouette clay loams, 0 to 6 percent slopes – clayey 10-14" np
209	Savageton-Silhouette clay loams, 6 to 15 percent slopes - clayey 10-14" np
210	Shingle-Taluce complex, 3 to 30 percent slopes – Shallow Clayey/Shallow Sandy 10-14" np
211	Shingle-Worf loams, 3 to 30 percent slopes – Shallow Clayey 10-14" np
213	Terro-Taluce sandy loams, 6 to 30 percent slopes – Sandy/Shallow Sandy 10-14" np
214	Theedle-Kishona loams, 0 to 6 percent slopes – Loamy 10-14" np
215	Theedle-Kishona loams, 6 to 20 percent slopes – Loamy 10-15" np
216	Theedle-Kishona-Shingle loams, 3 to 30 percent slopes - Loamy 10-14" np
217	Theedle-Shingle loams, 3 to 30 percent slopes – Loamy/Shallow Loamy 10-14" np
218	Theedle-Turnercrest-Kishona complex, 3 to 15 percent slopes – Loamy/Sandy 10-14" np
220	Pitchdraw-Ashollow-Niobrara complex, 3 to 30 percent slopes – Sandy 15-17" np
221	Turnercrest-Keeline-Taluce sandy loams, 6 to 30 percent slopes – Sandy 10-14" np
223	Ucross loam, 1 to 9 percent slopes – Loamy 15-17" np
224	Ucross-Iwait loams, 0 to 6 percent slopes – Loamy 15-17" np
225	Ucross-Iwait-Fairburn loams, 3 to 30 percent slopes - Loamy 15-17" np
227	Ulm clay loam, 0 to 6 percent slopes – Clayey 10-14" np
228	Ulm-Renohill clay loams, 0 to 6 percent slopes – Clayey 10-14" np
229	Ulm-Renohill clay loams, 6 to 15 percent slopes – Clayey 10-14" np
233	Ustic Torriorthents, gullied - Unspecified
235	Vonalee sandy loam, 0 to 10 percent slopes - Unspecified
236	Vonalee-Terro sandy loams, 2 to 10 percent slopes – Sandy 10-14" np
237	Vonalf sandy loam, 0 to 6 percent slopes – Sandy 15-17" np
238	Vonalf-Xema sandy loams, 3 to 10 percent slopes – Sandy 15-17" np
245	Wibaux-Shingle-Badlands complex, 6 to 60 percent slopes – Very Shallow/Shallow Loamy/Unspecified
246	Wyarno clay loams, 0 to 6 percent slopes – Clayey 10-14" np
247	Wyotite-Ulm loams, 0 to 6 percent slopes – Loamy 10-14" np
248	Ziggy-Iwait loams, 0 to 6 percent slopes – Loamy 15-17" np
249	Ziggy-Iwait loams, 6 to 15 percent slopes – Loamy 15-17" np
250	Ziggy-Ucross-Oldwolf loams, 3 to 15 percent slopes – Loamy 15-17" np
251	Water



Digitizing and GIS Mapwork conducted by
EDE Consultants
Environmental Engineering * Hydrology * Water Resources Engineering
23 N. Scott, Suite 23 Sheridan, WY (307) 672-3793

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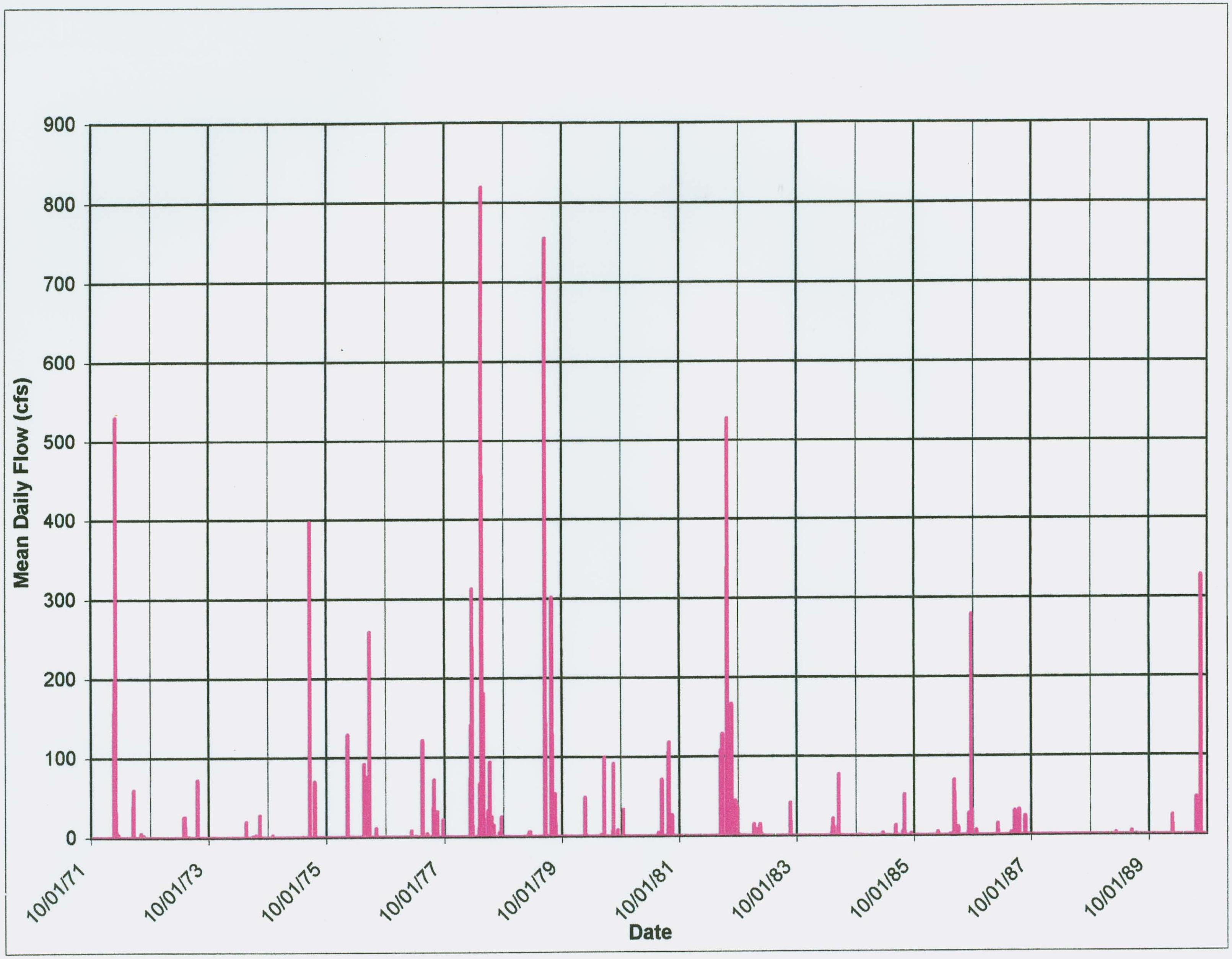
PROJECT NO. 01006

DEAD HORSE CREEK
WATERSHED SOILS

THREE HORSES
WATERSHED MASTER PLAN
WWDC LEVEL I STUDY

EnTech, Inc.
Consulting Engineers
Transportation Municipal Environmental Water Resources
1949 Sugarland Drive, Suite 205
Sheridan, Wyoming 82801
Phone 307-673-1542
Fax 307-673-1547
E-mail entech@entechusa.net

FIG. 2.1.6



EnTech, Inc.
Consulting Engineers
Transportation · Municipal · Environmental · Water Resources
1949 Sugarland Drive, Suite 205
Sheridan, Wyoming 82801
Phone 307-673-1542
Fax 307-673-1547
E-mail entech@entechusa.net

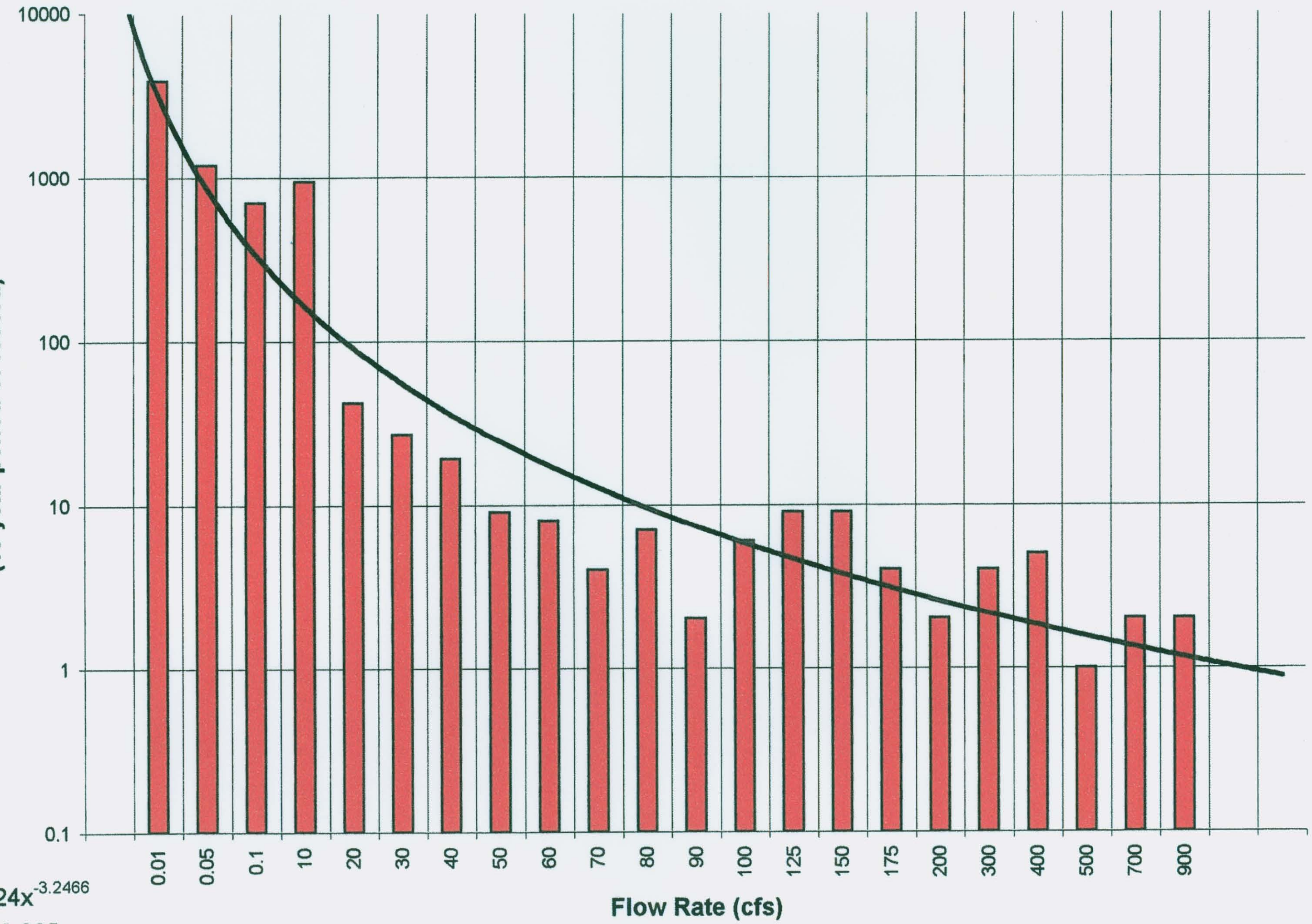
DEAD HORSE CREEK MEAN DAILY FLOW - 1971 TO 1990

FIG. 2.1.7

EnTech, Inc.
Consulting Engineers
Transportation • Municipal • Environmental • Water Resources
1949 Sugarland Drive, Suite 205
Sheridan, Wyoming 82801
Phone 307-673-1542
Fax 307-673-1547
E-mail entech@entechusa.net

FREQUENCY DISTRIBUTION OF OBSERVED USGS FLOWS-
DEAD HORSE CREEK

FIG. 2.1.8



$y = 30624x^{-3.2466}$
$R^2 = 0.885$

EnTech, Inc.
Consulting Engineers

TRILINEAR DIAGRAM - DEAD HORSE CREEK SURFACE AND GROUNDWATER QUALITY VALUES

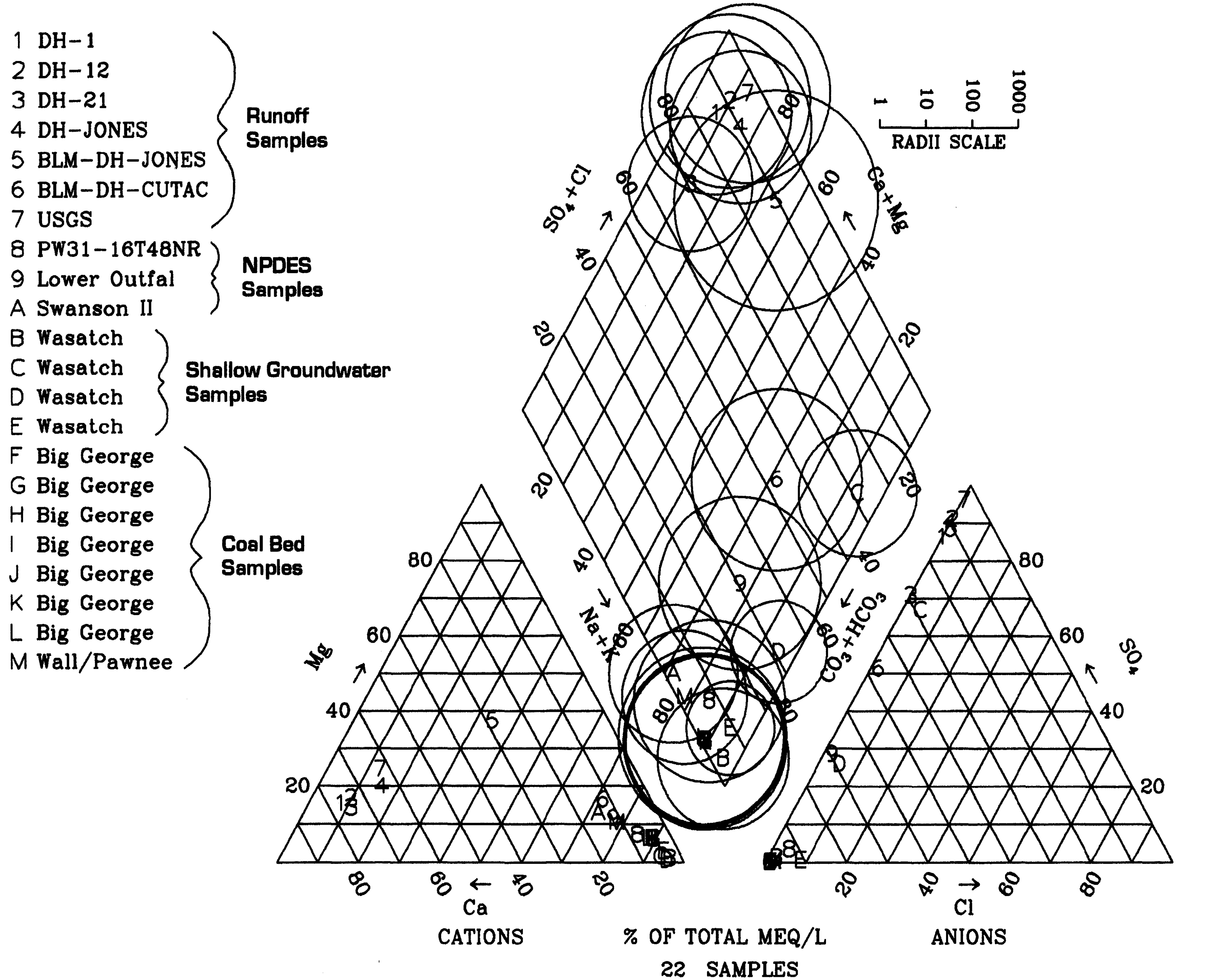


FIG. 2.1.9

EnTech, Inc.
Consulting Engineers
Transportation · Municipal · Environmental · Water Resources
1949 Sugarland Drive, Suite 205
Sheridan, Wyoming 82801
Phone 307-673-1542
Fax 307-673-1547
E-mail entech@entechusa.net

DEAD HORSE CREEK SURFACE WATER SAMPLES - JULY 23 AND 24, 2001

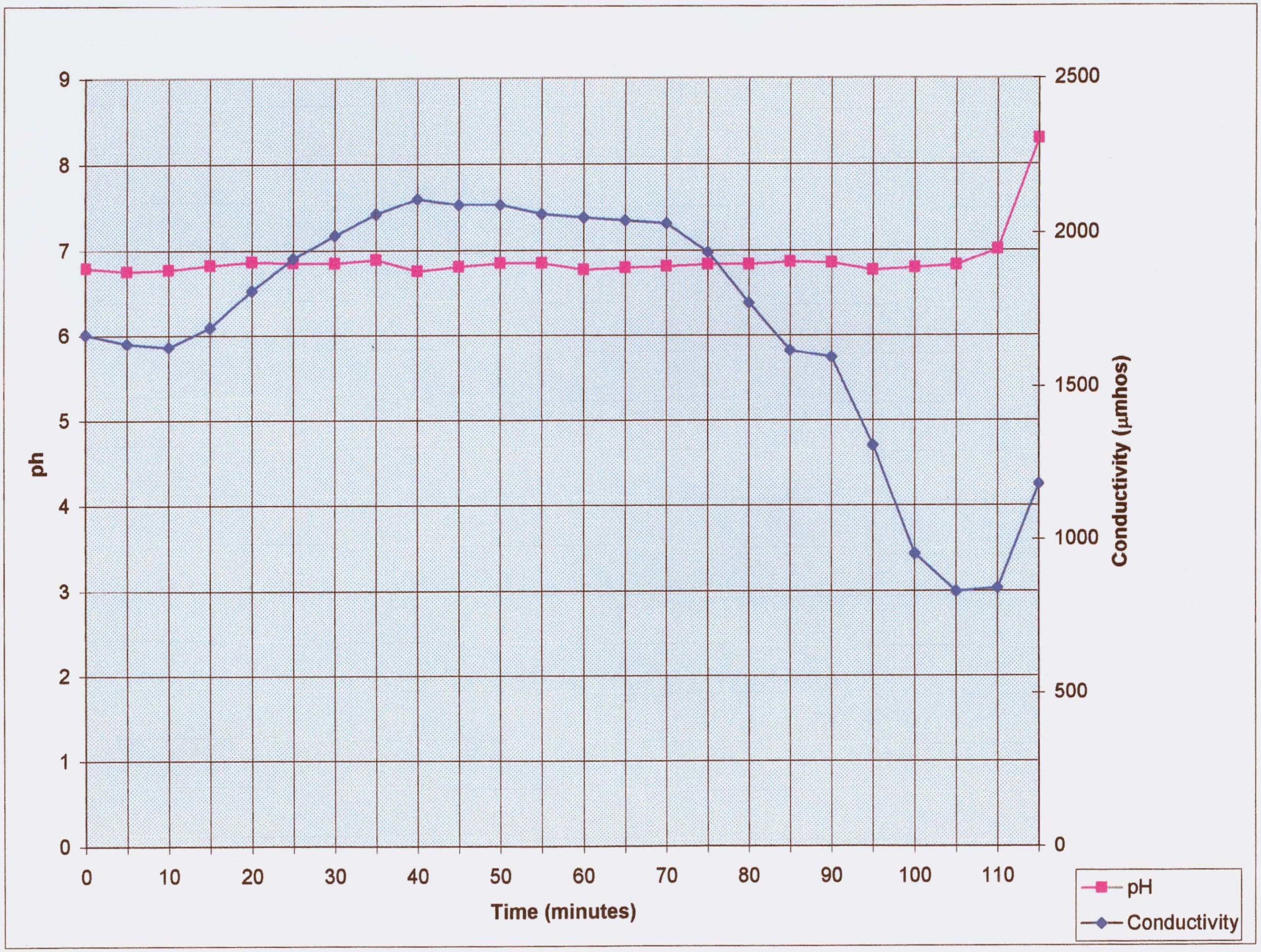
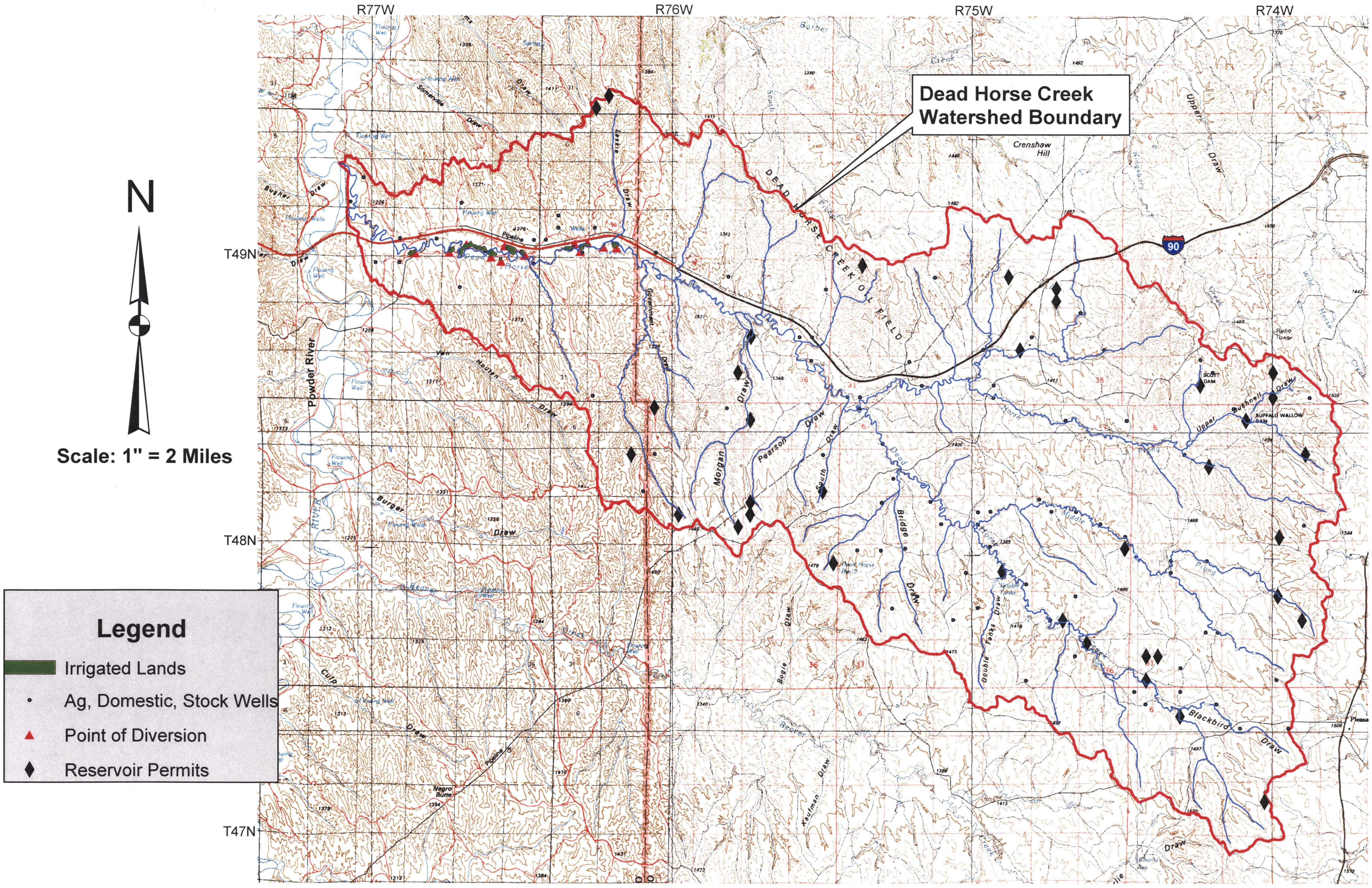


FIG. 2.1.10



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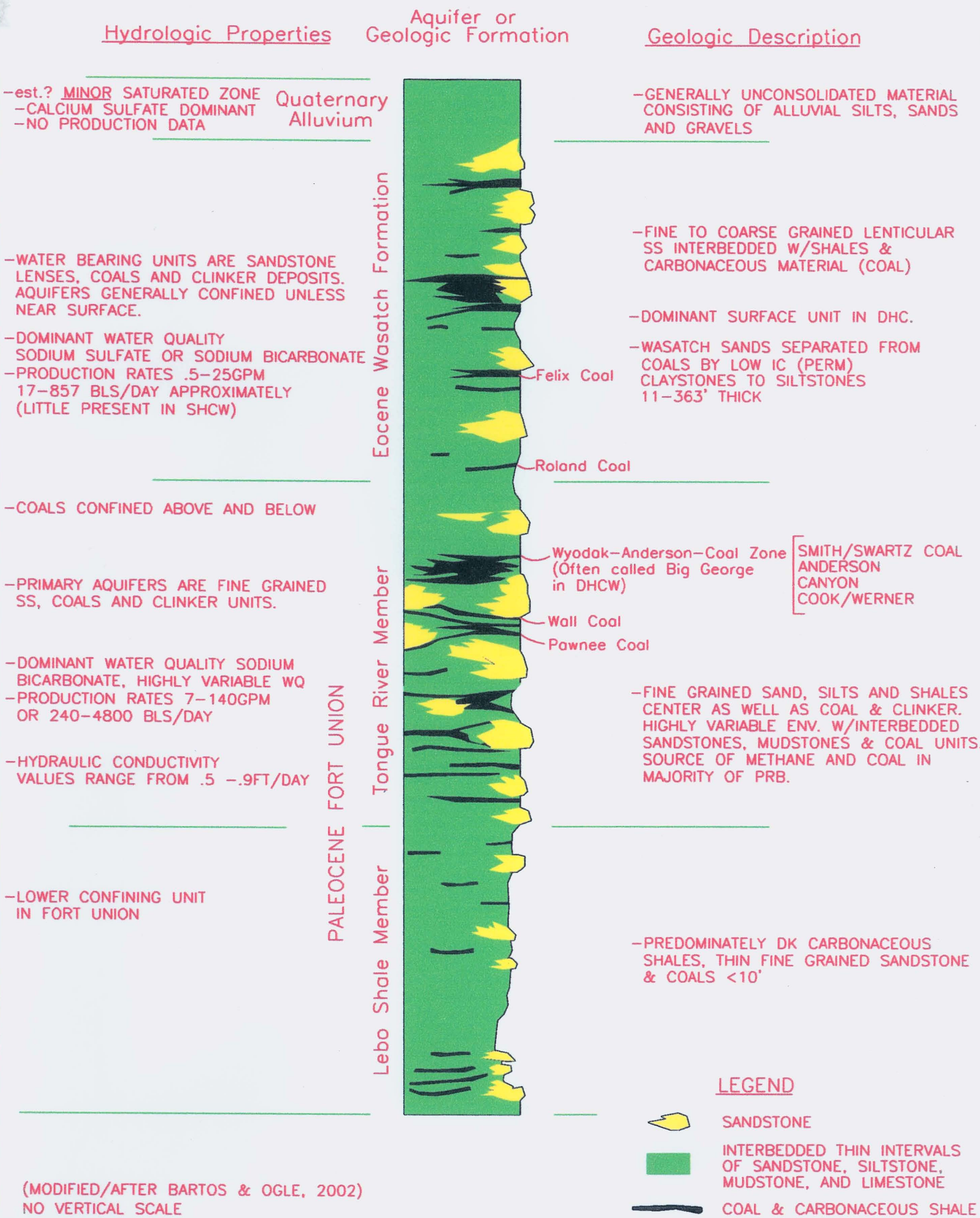
DEAD HORSE CREEK WATERSHED SURFACE WATER AND GROUNDWATER USE

THREE HORSES WATERSHED PLAN LEVEL I STUDY

EnTech, Inc.
Consulting Engineers
Transportation - Municipal - Environmental - Water Resources
1949 Sugarland Drive, Suite 205
Sheridan, Wyoming 82801
Phone 307-673-1542
Fax 307-673-1547
E-mail entech@entechusa.net

FIG. 2.1.11



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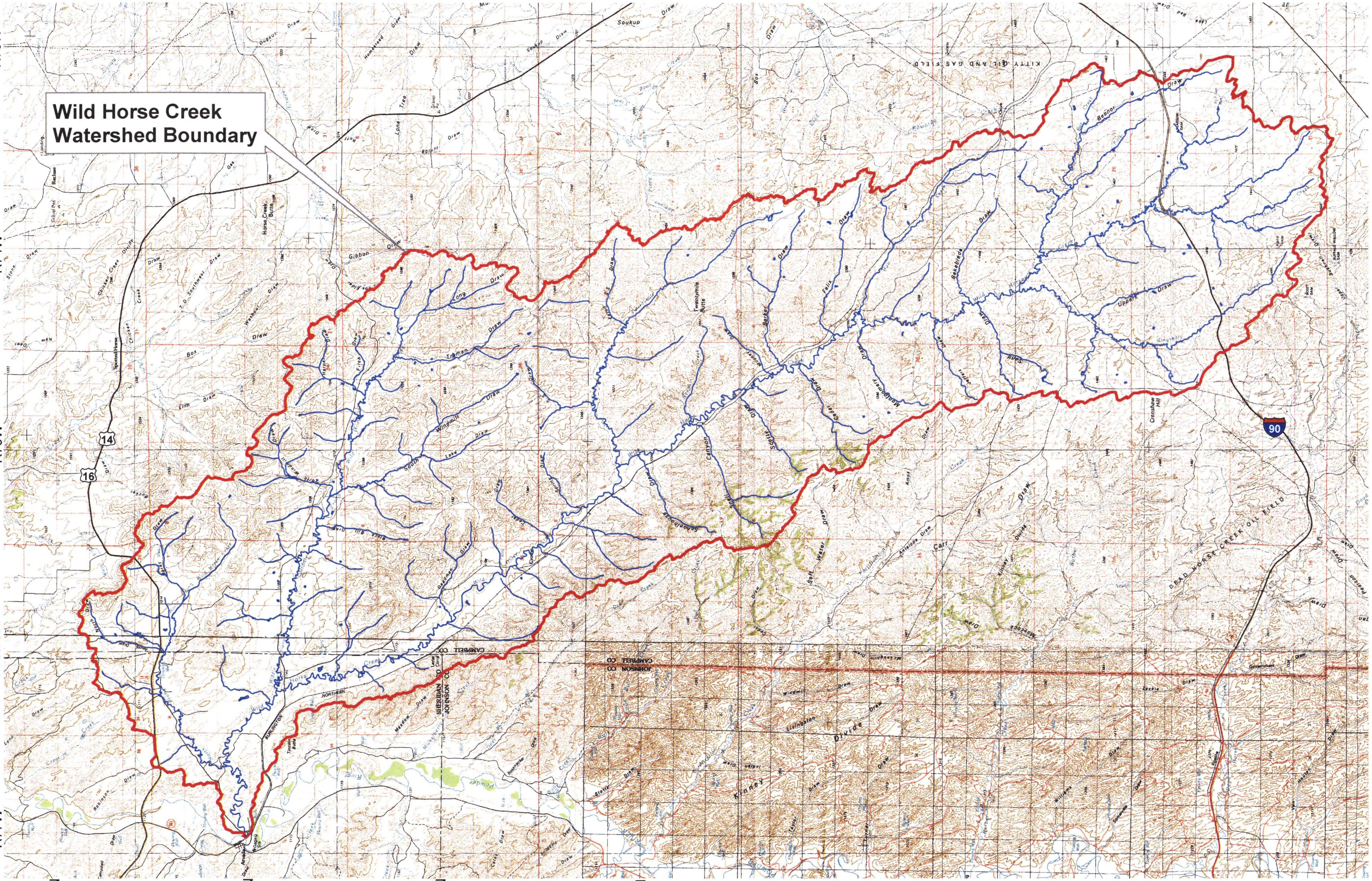
Consulting Engineers
Transportation·Municipal·Environmental·Water Resources
1949 Sugarland Drive, Suite 205
Sheridan, Wyoming 82801
Phone 307-673-1542
Fax 307-673-1547
E-mail entech@entechusa.net

THREE HORSES GENERALIZED HYDRO-STRATIGRAPHIC COLUMN

FIG. 2.1.12



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DATE				
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PROJECT NO. 01006

WILD HORSE CREEK
WATERSHED BOUNDARY

THREE HORSES
WATERSHED PLAN
LEVEL I STUDY

EnTech, Inc.
Consulting Engineers
Transportation - Municipal - Environmental - Water Resources

1949 Sugarland Drive, Suite 205
Sheridan, Wyoming 82801
Phone 307-673-1542
Fax 307-673-1547
E-mail entech@entechusa.net

FIG. 2.2.1

Wild Horse Creek Watershed
Soil and Range Site Map Legend

Map Symbol	Soil - Range Site Name
100	Aridic Ustorthents, saline, 0 to 4 percent slopes – Loamy 15-17" np
101	Arvada, thick surface, very fine sandy loam, 0 to 6 percent slopes – Loamy 10-14" np
102	Arvada, thick surface-Arvada-Slickspots complex, 0 to 6 percent slopes – Loamy/Saline Upland 10-14" np
103	Arwite sandy loam, 0 to 6 percent slopes – Sandy 15-17" np
104	Arwite sandy loam, 6 to 15 percent slopes – Sandy 15-17"np
105	Arwite-Elwop sandy loams, 0 to 6 percent slopes – Sandy 15-17" np
106	Arwite-Elwop sandy loams, 6 to 15 percent slopes – Sandy 15-17" np
107	Arwite-Vonalf sandy loams, 0 to 6 percent slopes – Sandy 15-17" np
108	Arwite-Vonalf sandy loams, 6 to15 percent slopes – Sandy 15-17" np
109	Bidman loam, 0 to 6 percent slopes – Loamy 10-14" np
111	Bidman-Parmleed loams, 0 to 6 percent slopes – Loamy 10-14" np
112	Bidman-Parmleed loams, 6 to 15 percent slopes – Loamy 10-14" np
114	Bowbac-Taluce-Badlands complex, 3 to 20 percent slopes –Sandy 10-14" np
116	Cambria-Kishona-Zigweid loams, 0 to 6 percent slopes – Loamy 10-14" np
117	Cambria-Kishona-Zigweid loams, 6 to 15 percent slopes –Loamy 10-14" np
121	Cushman-Cambria loams, 0 to 6 percent slopes – Loamy 10-14" np
122	Cushman-Cambria loams, 6 to 15 percent slopes – Loamy 10-14" np
124	Cushman-Shingle loams, 6 to 15 percent slopes – Loamy 10-14" np
127	Cushman-Theedle loams, 6 to 15 percent slopes – Loamy 10-14" np
128	Cushman-Worf loams, 3 to 15 percent slopes – Loamy/Shallow Loamy 10-14" np
130	Delconey-Hiland sandy loams, 6 to 15 percent slopes –Loamy 15-17" np
131	Deekay loam, 0 to 6 percent slopes –Loamy 15-17" np
132	Deekay-Moorhead loams, 0 to 6 percent slopes – Loamy 15-17" np
133	Deekay-Moorhead loams, 6 to 15 percent slopes – Loamy 15-17" np
134	Deekay-Oldwolf loams, 0 to 6 percent slopes – Loamy 15-17" np
135	Deekay-Oldwolf loams, 6 to 15 percent slopes – Loamy 15-17" np
136	Deekay-Ziggy loams, 0 to 6 percent slopes – Loamy 15-17" np
138	Echeta-Cromack clay loams, 6 to 15 percent slopes – Clayey 15-17" np
139	Embry-Orpha complex, 3 to 15 percent slopes – Sandy 10-14" np
140	Embry-Taluce sandy loams, 3 to 30 percent slopes – Sandy/Shallow Sandy 10-14" np
142	Emigha, sodic-Arvada, thick surface complex, 0 to 4 percent slopes – Saline Upland/Loamy 10-14" np
143	Felix clay, ponded, 0 to 2 percent slopes – Clayey Overflow 15-17" np
144	Forkwood loam, 0 to 6 percent slopes – Loamy 10-14" np
145	Forkwood-Cambria loams, 0 to 6 percent slopes – Loamy 10-14" np
146	Forkwood-Cushman loams, o to 6 percent slopes – Loamy 10-14" np
147	Forkwood-Cushman loams, 6 to 15 percent slopes – Loamy 10-14" np
148	Forkwood-Ulm loams, 0 to 6 percent slopes – Loamy 10-14" np
149	Forkwood-Ulm loams, 6 to 15 percent slopes – Loamy 10-14" np
153	Haverdad-Kishona association, 0 to 6 percent slopes – Lowland 10-14" np
155	Heldt-Bidman complex, saline, 0 to 3 percent slopes – Saline Upland/Loamy 10-14" np
157	Hiland-Bowbac sandy loams, 0 to 6 percent slopes – Sandy 10-14" np
158	Hiland-Bowbac sandy loams, 6 to 15 percent slopes – Sandy 10-14" np
159	Hiland-Vonalee sandy loams, 0 to 6 percent slopes - Sandy 10-14" np
160	Hiland-Vonalee sandy loams, 6 to 15 percent slopes – Sandy 10-14" np
164	Lismas-Sabatka-Badlands complex, 3 to 45 percent slopes – Shallow Clayey/Dense Clay 10-14" np
165	Jayem sandy loam, 6 to 20 percent slopes – Sandy/Loamy 15-17" np
166	Jaywest loam, 0 to 6 percent slopes – Loamy 15-17" np
167	Jaywest-Moorhead loams, 0 to 6 percent slopes – Loamy 15-17" np
168	Jaywest-Spottedhorse loams, 0 to 6 percent slopes – Loamy 15-17" np
169	Julesburg sandy loam, 0 to 6 percent slopes – Sandy 15-17" np
170	Keeline-Tullock loamy sands, 6 to 30 percent slopes – Sandy 10-14" np
171	Keeline-Tullock-Niobrara, dry, complex, 3 to 30 percent slopes – Sandy/Shallow Sandy 10-14" np
172	Keyner fine sandy loam, 0 to 6 percent slopes – Loamy 10-14" np
174	Brislawn-Rockybutte-Ironbutte complex, 0 to 10 percent slopes – Loamy 10-14" np
176	Leiter-Cromack clay loams, 3 to 15 percent slopes – Clayey 15-17" np
177	Maysdorf fine sandy loam, 0 to 6 percent slopes – Sandy 10-14" np
181	Moorhead clay loam, 0 to 6 percent slopes – Clayey 15-17" np
182	Moorhead loam, 0 to 6 percent slopes – Loamy 15-17" np
183	Moorhead-Leiter clay loams, 0 to 6 percent slopes – Clayey 15-17" np
184	Moorhead-Leiter clay loams, 6 to 15 percent slopes – Clayey 15-17" np
185	Moskee fine sandy loam, 0 to 6 percent slopes – Sandy 15-17" np
186	Moskee fine sandy loam, 6 to 10 percent slopes – Sandy 15-17" np
187	Nuncho loam, 0 to 6 percent slopes – Loamy 15-17" np
188	Orpha-Tullock loamy sands, 6 to 30 percent slopes – Sandy 10-14" np
189	Oshoto- Moorhead loams, 0 to 6 percent slopes – Loamy 15-17" np
192	Platmak loam, 0 to 6 percent slopes – Loamy 15-17" np
196	Rauzi sandy clay loam, 0 to 6 percent slopes – Loamy 15-17" np
198	Recluse loam, 0 to 6 percent slopes – Loamy 15-17" np
201	Renohill-Shingle-Worf complex, 3 to 15 percent slopes – Clayey/Shallow Loamy 10-14" np
202	Renohill-Worfka clay loams, 3 to 15 percent slopes – Clayey/Shallow Loamy 10-14" np
203	Rockypoint-Iwait association, 0 to 6 percent slopes – Lowland/Loamy 15-17" np
204	Samday-Samday Cool-Shingle clay loams, 6 to 40 percent slopes – Shallow Clayey/Very shallow 10-14" np
205	Samday-Savageton clay loams, 3 to 15 percent slopes – Clayey/Shallow Clayey 10-14" np
206	Samday-Shingle-Badlands complex, 10 to 45 percent slopes – Shallow Clayey/Shallow Loamy 10-14" np
207	Cromack-Fairburn-Ucross complex, 3 to 20 percent slopes – Clayey/Loamy 15-17" np
208	Savageton-Silhouette clay loams, 0 to 6 percent slopes – clayey 10-14" np
209	Savageton-Silhouette clay loams, 6 to 15 percent slopes - clayey 10-14" np
210	Shingle-Taluce complex, 3 to 30 percent slopes – Shallow Clayey/Shallow Sandy 10-14" np
211	Shingle-Worf loams, 3 to 30 percent slopes – Shallow Clayey 10-14" np
212	Teckla very fine sandy loams, 0 to 10 percent slopes – Loamy 10-14" np
213	Terro-Taluce sandy loams, 6 to 30 percent slopes – Sandy/Shallow Sandy 10-14" np
214	Theedle-Kishona loams, 0 to 6 percent slopes – Loamy 10-14" np
215	Theedle-Kishona loams, 6 to 20 percent slopes – Loamy 10-15" np
216	Theedle-Kishona-Shingle loams, 3 to 30 percent slopes - Loamy 10-14" np
217	Theedle-Shingle loams, 3 to 30 percent slopes – Loamy/Shallow Loamy 10-14" np
218	Theedle-Turnercrest-Kishona complex, 3 to 15 percent slopes – Loamy/Sandy 10-14" np
220	Pitchdraw-Ashollow-Niobrara complex, 3 to 30 percent slopes – Sandy 15-17" np
221	Turnercrest-Keeline-Taluce sandy loams, 6 to 30 percent slopes – Sandy 10-14" np
223	Ucross loam, 1 to 9 percent slopes – Loamy 15-17" np
224	Ucross-Iwait loams, 0 to 6 percent slopes – Loamy 15-17" np
225	Ucross-Iwait-Fairburn loams, 3 to 30 percent slopes - Loamy 15-17" np
227	Ulm clay loam, 0 to 6 percent slopes – Clayey 10-14" np
228	Ulm-Renohill clay loams, 0 to 6 percent slopes – Clayey 10-14" np
229	Ulm-Renohill clay loams, 6 to 15 percent slopes – Clayey 10-14" np
233	Ustic Torriorthents, gullied - Unspecified
235	Vonalee sandy loam, 0 to 10 percent slopes - Unspecified
236	Vonalee-Terro sandy loams, 2 to 10 percent slopes – Sandy 10-14" np
238	Vonalf-Xema sandy loams, 3 to 10 percent slopes – Sandy 15-17" np
239	Ironbutte-Fairburn-Mittenbutte complex, 6 to 40 percent slopes – Shallow Loamy 15-17" np
241	Ironbutte-Ironbutte thin solum loams, 6 to 40 percent slopes – Shallow Loamy/Very Shallow 10-14" np
242	Ironbutte-Deekay-Moorhead association, 3 to 30 percent slopes – Shallow Loamy/Loamy 15-17" np
244	Muleherder-Ironbutte channery loams, 3 to 30 percent slopes – Loamy/Shallow Loamy 15-17" np
248	Ziggy-Iwait loams, 0 to 6 percent slopes – Loamy 15-17" np
249	Ziggy-Iwait loams, 6 to 15 percent slopes – Loamy 15-17" np
250	Ziggy-Ucross-Oldwolf loams, 3 to 15 percent slopes – Loamy 15-17" np
251	Water
253	Absted-Arvada-Slickspots complex, 0 to 6 percent slopes – Saline Upland 10-14" np
255	Ulm-Bidman complex, 0 to 6 percent slopes – Clayey/Loamy 15-17" np
256	Bidman-Ulm, dry, complex, 0 to 6 percent slopes – Sandy 15-17" np
257	Coaliams loam, moderately saline, 0 to 3 percent slopes – Overflow 15-17" np
260	Foreleft-bonfri loams, 3 to 15 percent slopes – Loamy 15-17" np
261	Echeta-Moorhead clay loams, ponded, 0 to 2 percent slopes – Clayey 15-17" np
262	Felix clay, saline ponded, 0 to 2 percent slopes – Clayey 15-17"np
263	Rockypoint loam, 0 to 6 percent slopes – Lowland 15-17" np
264	Hiland-Bowbac association, 3 to 15 percent slopes – Sandy 10-14" np
265	Hiland-Delconey complex, 3 to 15 percent slopes – Sandy 10-14" np
266	Jaywest-jaywest stratified substratum, loams, 0 to 6 percent slopes – Loamy 15-17"np
267	Pinehill complex, 0 to 6 percent slopes – Loamy 15-17" np
268	Pinehill-Pylon loams, 3 to 15 percent slopes – Loamy 15-17" np
273	Nuncho clay loam, 0 to 6 percent slopes – Clayey 15-17" np
274	Oldwolf-Fairburn loams, 3 to 15 percent slopes – Loamy/shallow Loamy 15-17" np
275	Oshoto-Ziggy silt loams, 0 to 6 percent slopes – Loamy 15-17" np
277	Parmleed-Bidman association, 3 to 15 percent slopes – Loamy 10-14" np
278	Shingle-Taluce-Badlands complex, 6 to 45 percent slopes – Shallow Loamy 10-14" np
279	Silhouette-Ulm clay loams, 0 to 6 percent slopes – clayey 15-17" np
280	Spottedhorse-Leiter complex, 0 to 6 percent slopes – Loamy/Clayey 15-17" np
281	Delpoint-Yamacall-Cabbart loams, 3 to 30 percent slopes – Loamy 15-17" np
283	Ucross-Fairburn loams, 15 to 45 percent slopes – Loamy/Shallow Loamy 15-17" np
286	Ulm clay loam, dry, 3 to 6 percent slopes – Clayey 10-14" np
287	Ulm clay loam, 6 to 10 percent slopes – clayey 10-14" np
288	Vonalee-Terro-Taluce fine sandy loams, 3 to 30 percent slopes – Sandy 10-14" np
289	Vonalf-Xema-Mittenbutte fine sandy loams, 3 to 30 percent slopes – Sandy 15-17" np
292	Muleherder-Ironbutte, very stony complex, 10 to 60 percent slopes – Shallow Loamy 15-17" np
293	Muleherder-Ironbutte complex, range, 10 to 60 percent slopes – Shallow Loamy 15-17" np
294	Wibaux-Shingle-Taluce complex, 6 to 40 percent slopes – Shallow Loamy 10-14" np
298	Haverdad-Boruff complex, 0 to 6 percent slopes – Lowland 10-14" np
299	Rockypoint-Boruff complex, 0 to 6 percent slopes – Lowland 15-17" np
304	Haverdad clay loam, 0 to 3 percent slopes – Lowland 10-14" np
305	Cromack-Samsil clay loams, 3 to 15 percent slopes – Clayey/Shallow Clayey 15-17" np
306	Meganot_Yawdim clay loams, 3 to 15 percent slopes – Clayey/Shallow Clayey 15-17" np
307	Fairburn-Mittenbutte-Badlands complex, 6 to 45 percent slopes – Shallow Loamy/Shallow/Clayey 15-17" np
309	Cedarbutte-Slickspots complex, 0 to 6 percent slopes – Loamy/Saline 15-17" np
312	Fairburn-Samsil-Badlands complex, 6 to 45 percent slopes – Shallow Loamy/Shallow Clayey 15-17" np
313	Cabbart-Yawdim-Badlands complex, 6 to 45 percent slopes – Shallow Loamy/Shallow Clayey 15-17" np
314	Pitchdraw-Ashollow-Mittenbutte fine sandy loams, 3 to 30 percent slopes – Sandy 15-17" np
315	Hiland-Vonalee fine sandy loams, 0 to 6 percent slopes – Sandy 10-14" np
316	Swanboy-Cedarbutte-Slickspots complex, 0 to 6 percent slopes - Unspecified
317	Lismas-Sabatka-Xema complex, 3 to 25 percent slopes – Shallow Clayey/Clayey 15-17" np
320	Shingle-Taluce-Badlands complex, wooded, 3 to 25 percent slopes – Ponderosa Pine/Little Bluestem
324	Stetter clay, 0 to 6 percent slopes – Lowland 15-17" np
327	Bonfri-Twilight-Blacksheep fine sandy loams, wooded, 3 to 30 percent slopes – Woodland Suitability Group 15-17" np
330	Ironbutte-Fairburn-Mittenbutte complex, range, 6 to 40 percent slopes – Shallow Loamy 15-17" np
332	Wibaux-Shingle-Taluce complex, wooded, 6 to 40 percent slopes – Ponderosa Pine/Little Bluestem
337	Oshoto-Klinedraw silt loams, 0 to 6 percent slopes – Loamy 15-17" np
350	Abstad-Haverdad association, 0 to 6 percent slopes – Loamy 10-14" np
351	Bidman-Arvada fine sandy loams, 0 to 6 percent slopes – Loamy 10-14" np
352	Haverdad-Draknab complex, 0 to 3 percent slopes – Lowland 10-14" np
353	Haverdad-Worthenton complex, 0to 3 percent slopes – Lowland/Wetland
354	Renohill-Ulm, dry, 3 to 15 percent slopes – Clayey 10-14" np
355	Shingle-Haverdad association, 0 to 80 percent slopes – Shallow Loamy/Overflow 10-14" np
356	Shingle-Nihill complex, 3 to 80 percent slopes – Shallow Loamy 10-14" np
357	Shingle-Rock Outcrop complex, 30 to 50 percent slopes – Shallow Loamy 10-14" np
358	Shingle-Samday clay loams, 6 to 60 percent slopes – Shallow Loamy 10-14" np
359	Taluce-Tullock-vonalee association, 6 to 15 percent slopes – Shallow Sandy/Sandy 10-14" np
360	Worfka-Shingle-Samday complex, 6 to 30 percent slopes – Shallow Loamy 10-14" np
361	Wyarno clay loam, dry, 3 to 6 percent slopes – Clayey 10-14" np
362	Wyarno clay loam, 6 to 9 percent slopes – clayey 10-14" np
363	Forkwood loam, 6 to 9 percent slopes – Loamy 10-14" np
364	Kishona-Cambria complex, 3 to 6 percent slopes – Loamy 10-14" np
365	Parmaleed-Renohill complex, moist, 3 to 9 percent slopes – Loamy/Clayey 10-14" np
366	Parmaleed-renohill complex, 9 to 25 percent slopes – Loamy/Clayey 10-14" np
367	Parmaleed-Worfka association, 0 to 15 percent slopes – Loamy 10-14" np
368	Reget silt loam, 0 to 6 percent slopes – Clayey 15-17" np
369	Searing-Ringling association, 2 to 75 percent slopes – Loamy/Shallow Loamy 15-17" np
370	Shingle-Samday clay loams, moist, 3 to 55 percent slopes – Shallow Loamy/Shallow Clayey 15-17" np
371	Shingle-Theedle complex, 45 to 75 percent slopes, Shallow Loamy/Loamy 10-14" np
372	Shingle-Worf complex, 6 to 15 percent slopes – Shallow Loamy 10-14" np
373	Taluce-Tullock-Vonalee association, moist, 9 to 30 percent slopes – Shallow Sandy/Sandy 15-17" np
374	Twin Creek Variant silt loam, 0 to 3 percent slopes - Subirrigated

Note: 4-digit numbers are unidentified and are treated here as miscellaneous soils
Some polygons may be missing a number,; they are treated as miscellaneous soils

Digitizing and GIS Mapwork conducted by

EDE Consultants
Environmental Engineering * Hydrology * Water Resources Engineering

23 N. Scott, Suite 23 Sheridan, WY (307) 672-3793

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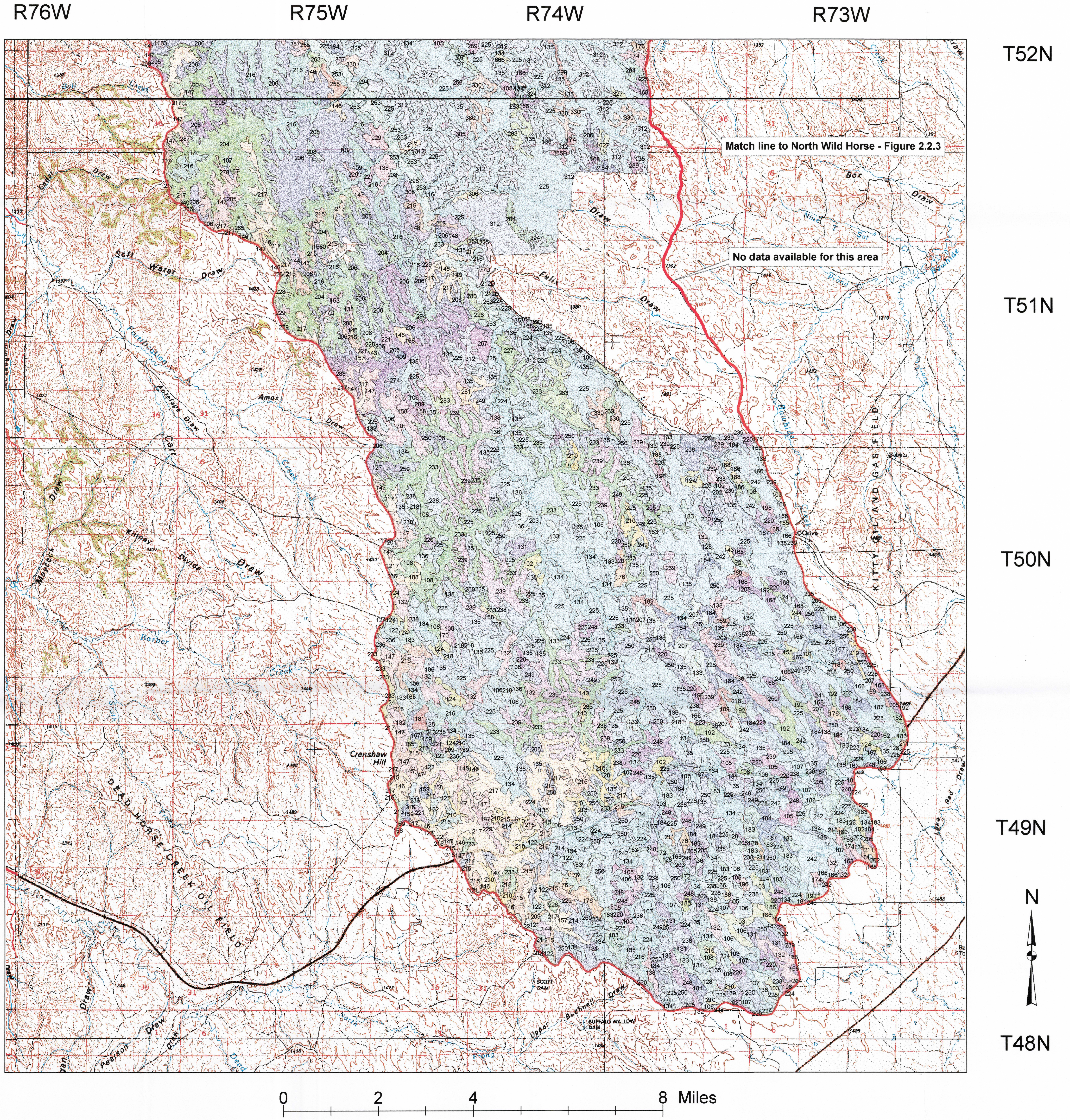

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PROJECT NO. 01006

WILD HORSE CREEK
WATERSHED SOILS (SOUTH)

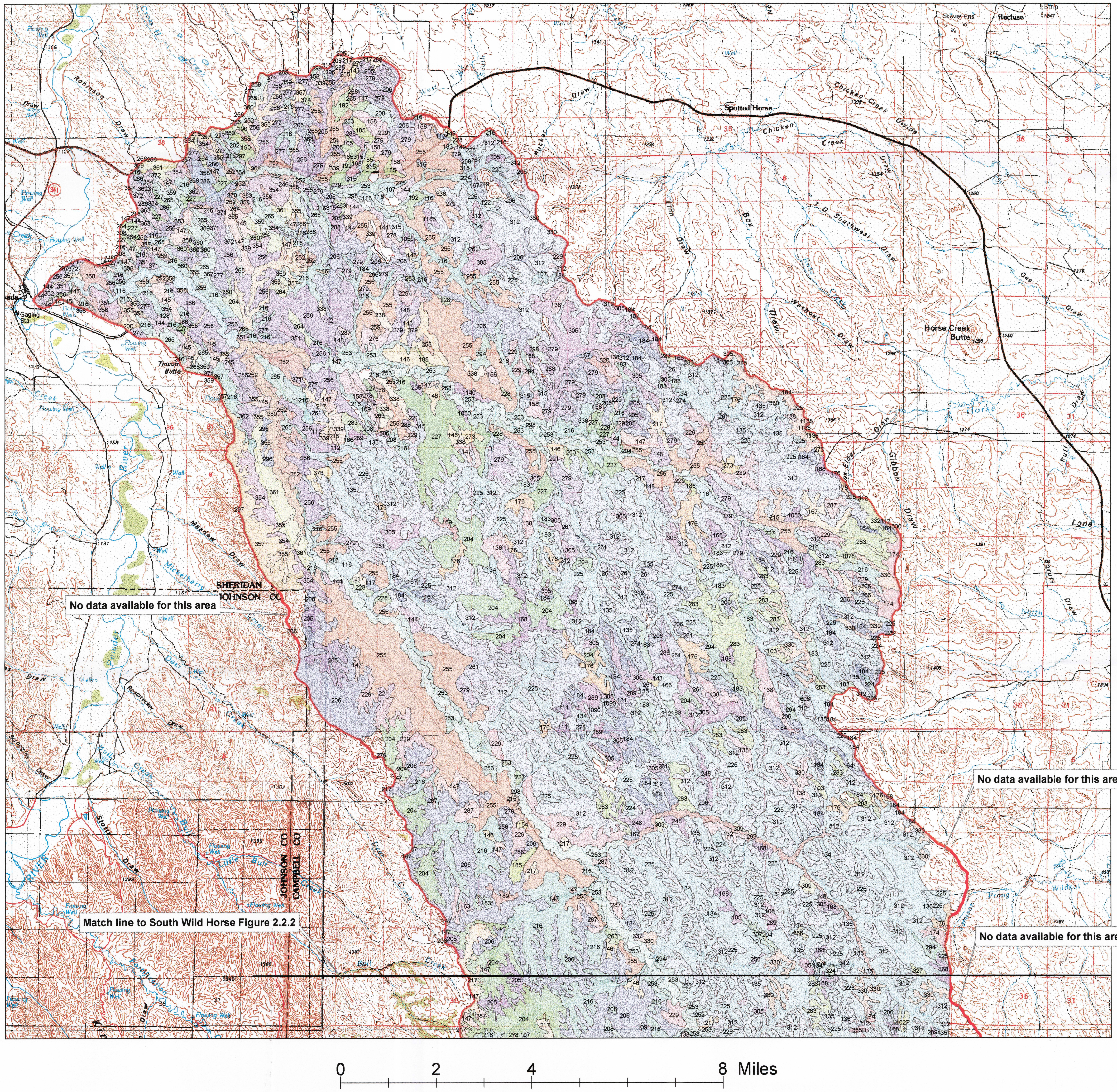
THREE HORSES
WATERSHED MASTER PLAN
WWDC LEVEL I STUDY

EnTech, Inc.
Consulting Engineers
Transportation Municipal Environmental Water Resources
1949 Sugarland Drive, Suite 205
Sheridan, Wyoming 82801
Phone 307-673-1542
Fax 307-673-1547
E-mail entech@entechusa.net

FIG. 2.2.2

Wild Horse Creek Watershed
Soil and Range Site Map Legend

Map Symbol	Soil - Range Site Name
100	Aridic Ustorthents, saline, 0 to 4 percent slopes – Loamy 15-17" np
101	Arvada, thick surface, very fine sandy loam, 0 to 6 percent slopes – Loamy 10-14" np
102	Arvada, thick surface-Arvada-Slickspots complex, 0 to 6 percent slopes – Loamy/Saline Upland 10-14" np
103	Arwite sandy loam, 0 to 6 percent slopes – Sandy 15-17" np
104	Arwite sandy loam, 6 to 15 percent slopes – Sandy 15-17"np
105	Arwite-Elwop sandy loams, 0 to 6 percent slopes – Sandy 15-17" np
106	Arwite-Elwop sandy loams, 6 to 15 percent slopes – Sandy 15-17" np
107	Arwite-Vonalf sandy loams, 0 to 6 percent slopes – Sandy 15-17" np
108	Arwite-Vonalf sandy loams, 6 to15 percent slopes – Sandy 15-17" np
109	Bidman loam, 0 to 6 percent slopes – Loamy 10-14" np
111	Bidman-Parmleed loams, 0 to 6 percent slopes – Loamy 10-14" np
112	Bidman-Parmleed loams, 6 to 15 percent slopes – Loamy 10-14" np
114	Bowbac-Taluce-Badlands complex, 3 to 20 percent slopes –Sandy 10-14" np
116	Cambria-Kishona-Zigweid loams, 0 to 6 percent slopes – Loamy 10-14" np
117	Cambria-Kishona-Zigweid loams, 6 to 15 percent slopes –Loamy 10-14" np
121	Cushman-Cambria loams, 0 to 6 percent slopes – Loamy 10-14" np
122	Cushman-Cambria loams, 6 to 15 percent slopes – Loamy 10-14" np
124	Cushman-Shingle loams, 6 to 15 percent slopes – Loamy 10-14" np
127	Cushman-Theedle loams, 6 to 15 percent slopes – Loamy 10-14" np
128	Cushman-Worf loams, 3 to 15 percent slopes – Loamy/Shallow Loamy 10-14" np
130	Delconey-Hiland sandy loams, 6 to 15 percent slopes –Loamy 15-17" np
131	Deekay loam, 0 to 6 percent slopes –Loamy 15-17" np
132	Deekay-Moorhead loams, 0 to 6 percent slopes – Loamy 15-17" np
133	Deekay-Moorhead loams, 6 to 15 percent slopes – Loamy 15-17" np
134	Deekay-Oldwolf loams, 0 to 6 percent slopes – Loamy 15-17" np
135	Deekay-Oldwolf loams, 6 to 15 percent slopes – Loamy 15-17" np
136	Deekay-Ziggy loams, 0 to 6 percent slopes – Loamy 15-17" np
138	Echeta-Cromack clay loams, 6 to 15 percent slopes – Clayey 15-17" np
139	Embry-Orpha complex, 3 to 15 percent slopes – Sandy 10-14" np
140	Embry-Taluce sandy loams, 3 to 30 percent slopes – Sandy/Shallow Sandy 10-14" np
142	Emigha, sodic-Arvada, thick surface complex, 0 to 4 percent slopes – Saline Upland/Loamy 10-14" np
143	Felix clay, ponded, 0 to 2 percent slopes – Clayey Overflow 15-17" np
144	Forkwood loam, 0 to 6 percent slopes – Loamy 10-14" np
145	Forkwood-Cambria loams, 0 to 6 percent slopes – Loamy 10-14" np
146	Forkwood-Cushman loams, o to 6 percent slopes – Loamy 10-14" np
147	Forkwood-Cushman loams, 6 to 15 percent slopes – Loamy 10-14" np
148	Forkwood-Ulm loams, 0 to 6 percent slopes – Loamy 10-14" np
149	Forkwood-Ulm loams, 6 to 15 percent slopes – Loamy 10-14" np
153	Haverdad-Kishona association, 0 to 6 percent slopes – Lowland 10-14" np
155	Heldt-Bidman complex, saline, 0 to 3 percent slopes – Saline Upland/Loamy 10-14" np
157	Hiland-Bowbac sandy loams, 0 to 6 percent slopes – Sandy 10-14" np
158	Hiland-Bowbac sandy loams, 6 to 15 percent slopes – Sandy 10-14" np
159	Hiland-Vonalee sandy loams, 0 to 6 percent slopes - Sandy 10-14" np
160	Hiland-Vonalee sandy loams, 6 to 15 percent slopes – Sandy 10-14" np
164	Lismas-Sabatka-Badlands complex, 3 to 45 percent slopes – Shallow Clayey/Dense Clay 10-14" np
165	Jayem sandy loam, 6 to 20 percent slopes – Sandy/Loamy 15-17" np
166	Jaywest loam, 0 to 6 percent slopes – Loamy 15-17" np
167	Jaywest-Moorhead loams, 0 to 6 percent slopes – Loamy 15-17" np
168	Jaywest-Spottedhorse loams, 0 to 6 percent slopes – Loamy 15-17" np
169	Julesburg sandy loam, 0 to 6 percent slopes – Sandy 15-17" np
170	Keeline-Tullock loamy sands, 6 to 30 percent slopes – Sandy 10-14" np
171	Keeline-Tullock-Niobrara, dry, complex, 3 to 30 percent slopes – Sandy/Shallow Sandy 10-14" np
172	Keyner fine sandy loam, 0 to 6 percent slopes – Loamy 10-14" np
174	Brislawn-Rockybutte-Ironbutte complex, 0 to 10 percent slopes – Loamy 10-14" np
176	Leiter-Cromack clay loams, 3 to 15 percent slopes – Clayey 15-17" np
177	Maysdorf fine sandy loam, 0 to 6 percent slopes – Sandy 10-14" np
181	Moorhead clay loam, 0 to 6 percent slopes – Clayey 15-17" np
182	Moorhead loam, 0 to 6 percent slopes – Loamy 15-17" np
183	Moorhead-Leiter clay loams, 0 to 6 percent slopes – Clayey 15-17" np
184	Moorhead-Leiter clay loams, 6 to 15 percent slopes – Clayey 15-17" np
185	Moskee fine sandy loam, 0 to 6 percent slopes – Sandy 15-17" np
186	Moskee fine sandy loam, 6 to 10 percent slopes – Sandy 15-17" np
187	Nuncho loam, 0 to 6 percent slopes – Loamy 15-17" np
188	Orpha-Tullock loamy sands, 6 to 30 percent slopes – Sandy 10-14" np
189	Oshoto- Moorhead loams, 0 to 6 percent slopes – Loamy 15-17" np
192	Platmak loam, 0 to 6 percent slopes – Loamy 15-17" np
196	Rauzi sandy clay loam, 0 to 6 percent slopes – Loamy 15-17" np
198	Recluse loam, 0 to 6 percent slopes – Loamy 15-17" np
201	Renohill-Shingle-Worf complex, 3 to 15 percent slopes – Clayey/Shallow Loamy 10-14" np
202	Renohill-Worfka clay loams, 3 to 15 percent slopes – Clayey/Shallow Loamy 10-14" np
203	Rockypoint-Iwait association, 0 to 6 percent slopes – Lowland/Loamy 15-17" np
204	Samday-Samday Cool-Shingle clay loams, 6 to 40 percent slopes – Shallow Clayey/Very shallow 10-14" np
205	Samday-Savageton clay loams, 3 to 15 percent slopes – Clayey/Shallow Clayey 10-14" np
206	Samday-Shingle-Badlands complex, 10 to 45 percent slopes – Shallow Clayey/Shallow Loamy 10-14" np
207	Cromack-Fairburn-Ucross complex, 3 to 20 percent slopes – Clayey/Loamy 15-17" np
208	Savageton-Silhouette clay loams, 0 to 6 percent slopes – clayey 10-14" np
209	Savageton-Silhouette clay loams, 6 to 15 percent slopes - clayey 10-14" np
210	Shingle-Taluce complex, 3 to 30 percent slopes – Shallow Clayey/Shallow Sandy 10-14" np
211	Shingle-Worf loams, 3 to 30 percent slopes – Shallow Clayey 10-14" np
212	Teckla very fine sandy loams, 0 to 10 percent slopes – Loamy 10-14" np
213	Terro-Taluce sandy loams, 6 to 30 percent slopes – Sandy/Shallow Sandy 10-14" np
214	Theedle-Kishona loams, 0 to 6 percent slopes – Loamy 10-14" np
215	Theedle-Kishona loams, 6 to 20 percent slopes – Loamy 10-15" np
216	Theedle-Kishona-Shingle loams, 3 to 30 percent slopes - Loamy 10-14" np
217	Theedle-Shingle loams, 3 to 30 percent slopes – Loamy/Shallow Loamy 10-14" np
218	Theedle-Turnercrest-Kishona complex, 3 to 15 percent slopes – Loamy/Sandy 10-14" np
220	Pitchdraw-Ashollow-Niobrara complex, 3 to 30 percent slopes – Sandy 15-17" np
221	Turnercrest-Keeline-Taluce sandy loams, 6 to 30 percent slopes – Sandy 10-14" np
223	Ucross loam, 1 to 9 percent slopes – Loamy 15-17" np
224	Ucross-Iwait loams, 0 to 6 percent slopes – Loamy 15-17" np
225	Ucross-Iwait-Fairburn loams, 3 to 30 percent slopes - Loamy 15-17" np
227	Ulm clay loam, 0 to 6 percent slopes – Clayey 10-14" np
228	Ulm-Renohill clay loams, 0 to 6 percent slopes – Clayey 10-14" np
229	Ulm-Renohill clay loams, 6 to 15 percent slopes – Clayey 10-14" np
233	Ustic Torriorthents, gullied - Unspecified
235	Vonalee sandy loam, 0 to 10 percent slopes - Unspecified
236	Vonalee-Terro sandy loams, 2 to 10 percent slopes – Sandy 10-14" np
238	Vonalf-Xema sandy loams, 3 to 10 percent slopes – Sandy 15-17" np
239	Ironbutte-Fairburn-Mittenbutte complex, 6 to 40 percent slopes – Shallow Loamy 15-17" np
240	Ironbutte thin solum loams, 6 to 40 percent slopes – Shallow Loamy/Very Shallow 10-14" np
242	Ironbutte-Fairburn-Moorhead association, 3 to 30 percent slopes – Shallow Loamy/Loamy 15-17" np
243	Muleherder-Ironbutte channery loams, 3 to 30 percent slopes – Loamy/Shallow Loamy 15-17" np
248	Ziggy-Iwait loams, 0 to 6 percent slopes – Loamy 15-17" np
249	Ziggy-Iwait loams, 6 to 15 percent slopes – Loamy 15-17" np
250	Ziggy-Ucross-Oldwolf loams, 3 to 15 percent slopes – Loamy 15-17" np
251	Water
252	Abstad-Arvada-Slickspots complex, 0 to 6 percent slopes – Saline Upland 10-14" np
253	Ulm-Bidman complex, 0 to 6 percent slopes – Clayey/Loamy 15-17" np
255	Bidman-Ulm, dry, complex, 0 to 6 percent slopes – Sandy 15-17" np
256	Coalsams loam, moderately saline, 0 to 3 percent slopes – Overflow 15-17" np
257	[illegible]
260	Echeta-Moorhead clay loams, ponded, 0 to 2 percent slopes – Clayey 15-17" np
261	Felix clay, saline ponded, 0 to 2 percent slopes – Clayey 15-17" np
262	Rockypoint loam, 0 to 6 percent slopes – Lowland 15-17" np
263	Hiland-Bowbac association, 3 to 15 percent slopes – Sandy 10-14" np
264	Hiland-Delconey complex, 3 to 15 percent slopes – Sandy 10-14" np
265	Jaywest-Jaywest stratified substratum, loams, 0 to 6 percent slopes – Loamy 15-17" np
266	Pinehill complex, 0 to 6 percent slopes – Loamy 15-17" np
267	Pinehill-Pylon loams, 3 to 15 percent slopes – Loamy 15-17" np
272	Nuncho clay loam, 0 to 6 percent slopes – Clayey 15-17" np
273	Oldwolf-Fairburn loams, 3 to 15 percent slopes – Loamy/Shallow Loamy 15-17" np
274	Oshoto-Ziggy silt loams, 0 to 6 percent slopes – Loamy 15-17" np
275	Parmleed-Bidman association, 0 to 15 percent slopes – Loamy 10-14" np
276	Shingle-Taluce-Badlands complex, 6 to 45 percent slopes – Shallow Loamy 10-14" np
277	Silhouette-Ulm clay loams, 0 to 6 percent slopes – clayey 10-14" np
278	Spottedhorse-Leiter complex, 0 to 6 percent slopes – Loamy/Clayey 15-17" np
279	Delpoint-Yamacall-Cabbart loams, 3 to 30 percent slopes – Loamy 15-17" np
280	Ucross-Fairburn loams, 15 to 45 percent slopes – Loamy/Shallow Loamy 15-17" np
281	Ulm clay loam, dry, 3 to 6 percent slopes – Clayey 10-14" np
282	Ulm clay loam, 6 to 10 percent slopes – Clayey 10-14" np
283	Vonalee-Terro-Taluce fine sandy loams, 3 to 30 percent slopes – Sandy 10-14" np
284	Vonalf-Xema-Mittenbutte fine sandy loams, 3 to 30 percent slopes – Sandy 15-17" np
285	Muleherder-Ironbutte, very stony complex, 10 to 60 percent slopes – Shallow Loamy 15-17" np
286	Muleherder-Ironbutte complex, range, 10 to 60 percent slopes – Shallow Loamy 15-17" np
287	Wibaux-Shingle-Taluce complex, 6 to 40 percent slopes – Shallow Loamy 10-14" np
288	Haverdad-Bonuff complex, 0 to 6 percent slopes – Lowland 10-14" np
289	Rockypoint-Bonuff complex, 0 to 6 percent slopes – Lowland 15-17" np
304	Haverdad clay loam, 0 to 3 percent slopes – Lowland 10-14" np
305	Cromack-Samsil clay loams, 3 to 15 percent slopes – Clayey/Shallow Clayey 15-17" np
306	Megonot, Yawdim clay loams, 3 to 15 percent slopes – Clayey/Shallow Clayey 15-17" np
307	Fairburn-Mittenbutte-Badlands complex, 6 to 45 percent slopes – Shallow Loamy/Shallow/Clayey 15-17" np
308	Cedarbutte-Slickspots complex, 0 to 6 percent slopes – Loamy/Saline 15-17" np
312	Fairburn-Samsil-Badlands complex, 6 to 45 percent slopes – Shallow Loamy/Shallow Clayey 15-17" np
313	Cabbart-Yawdim-Badlands complex, 6 to 45 percent slopes – Shallow Loamy/Shallow Clayey 15-17" np
314	Pitchdraw-Ashollow-Mittenbutte fine sandy loams, 3 to 30 percent slopes – Sandy 15-17" np
315	Hiland-Vonalee fine sandy loams, 0 to 6 percent slopes – Sandy 10-14" np
316	Swanboy-Cedarbutte-Slickspots complex, 0 to 6 percent slopes – Unspecified
317	Lismas-Sabatka-Xema complex, 3 to 25 percent slopes – Shallow Clayey/Clayey 15-17" np
320	Shingle-Taluce-Badlands complex, wooded, 3 to 25 percent slopes – Ponderosa Pine/Little Bluestem
321	Butte clay, 0 to 6 percent slopes – Lowland 15-17" np
330	Bendo-Twilight-Blackhawk fine sandy loams, wooded, 3 to 30 percent slopes – Woodland Suitability Group 15-17" np
331	Ironbutte-Fairburn-Mittenbutte complex, range, 6 to 40 percent slopes – Shallow Loamy 15-17" np
332	Wibaux-Shingle-Taluce complex, wooded, 6 to 40 percent slopes – Ponderosa Pine/Little Bluestem
337	Oshoto-Klinedane silt loams, 0 to 6 percent slopes – Loamy 15-17" np
350	Abstad-Haverdad association, 0 to 6 percent slopes – Loamy 10-14" np
351	Bidman-Arvada fine sandy loams, 0 to 6 percent slopes – Loamy 10-14" np
352	Haverdad-Draknab complex, 0 to 3 percent slopes – Lowland 10-14" np
353	Haverdad-Worthenton complex, 0 to 3 percent slopes – Lowland/Wetland
354	Renohill-Ulm, dry, 3 to 15 percent slopes – Clayey 10-14" np
355	Shingle-Haverdad association, 0 to 80 percent slopes – Shallow Loamy/Overflow 10-14" np
356	Shingle-Nihill complex, 3 to 80 percent slopes – Shallow Loamy 10-14" np
357	Shingle-Rock Outcrop complex, 30 to 50 percent slopes – Shallow Loamy 10-14" np
358	Shingle-Samday clay loams, 6 to 60 percent slopes – Shallow Loamy 10-14" np
359	Taluce-Tullock-Vonalee association, 6 to 15 percent slopes – Shallow Sandy/Sandy 10-14" np
360	Worfka-Shingle-Samday complex, 6 to 30 percent slopes – Shallow Loamy 10-14" np
361	Wyarno clay loam, dry, 3 to 6 percent slopes – Clayey 10-14" np
362	Wyarno clay loam, 6 to 9 percent slopes – clayey 10-14" np
363	Forkwood loam, 6 to 9 percent slopes – Loamy 10-14" np
364	Kishona-Cambria complex, 3 to 6 percent slopes – Loamy 10-14" np
365	Parmleed-Renohill complex, moist, 3 to 9 percent slopes – Loamy/Clayey 10-14" np
366	Parmleed-renohill complex, 9 to 25 percent slopes – Loamy/Clayey 10-14" np
367	Parmleed-Worfka association, 0 to 15 percent slopes – Loamy 10-14" np
368	Ragel silt loam, 0 to 6 percent slopes – Clayey 15-17" np
369	Searing-Ringling association, 2 to 75 percent slopes – Shallow Loamy 15-17" np
370	Shingle-Samday clay loams, moist, 3 to 55 percent slopes – Shallow Loamy/Shallow Clayey 15-17" np
371	Shingle-Theedle complex, 45 to 75 percent slopes, Shallow Loamy 10-14" np
372	Shingle-Worf complex, 6 to 15 percent slopes – Shallow Loamy 10-14" np
373	Taluce-Tullock-Vonalee association, moist, 9 to 30 percent slopes – Shallow Sandy/Sandy 15-17" np
374	Twin Creek Variant silt loam, 0 to 3 percent slopes – Subirrigated
Note	4-digit numbers are unidentified and are treated here as miscellaneous soils. Some polygons may be missing a number; they are treated as miscellaneous soils



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23 N. Scott, Suite 23 Sheridan, WY (307) 672-3793

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PROJECT NO. 01006

WILD HORSE CREEK
WATERSHED SOILS (NORTH)

THREE HORSES
WATERSHED MASTER PLAN
WWDC LEVEL I STUDY

EnTech, Inc.
Consulting Engineers

FIG. 2.2.3

EnTech, Inc.
Consulting Engineers

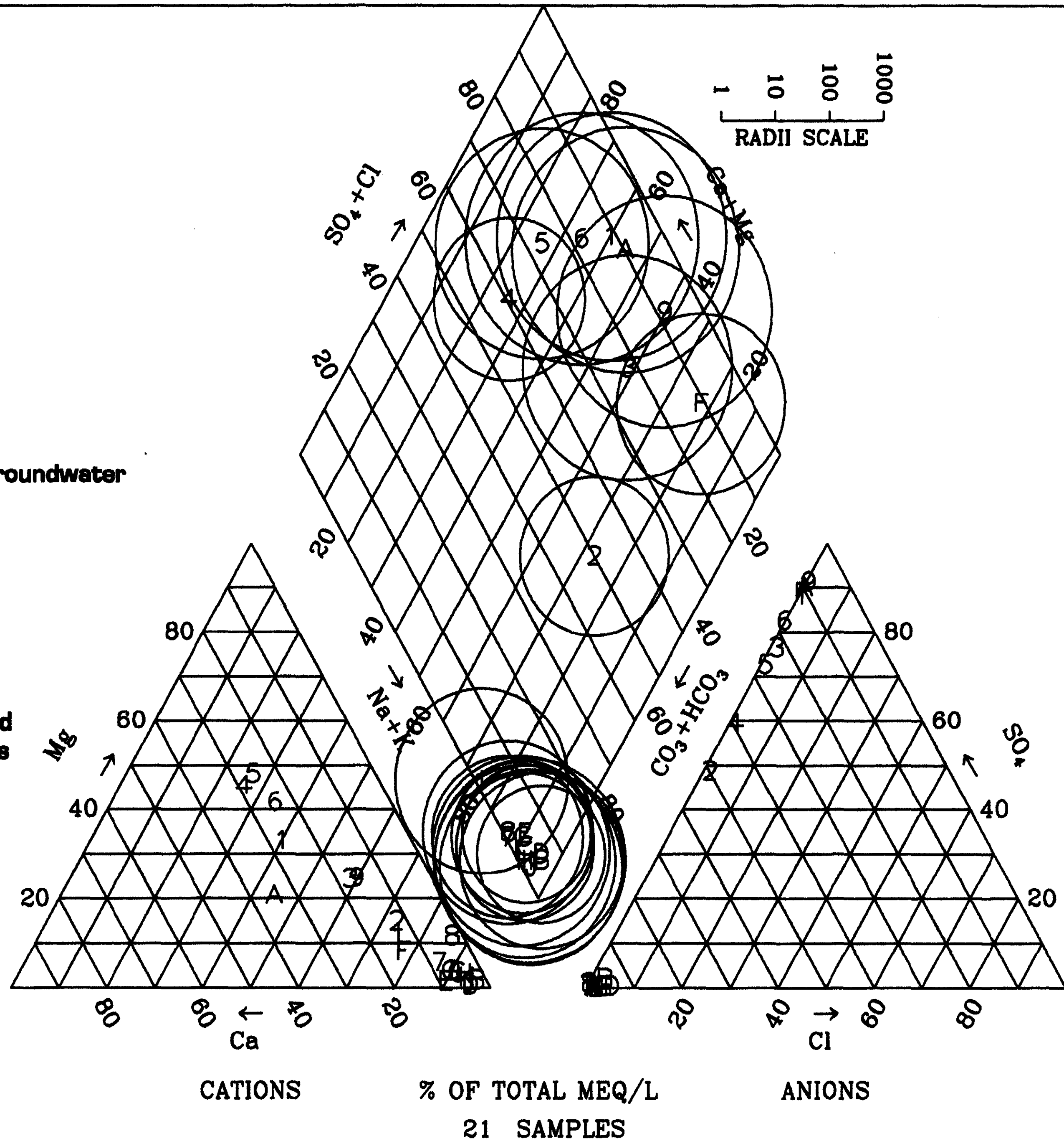
TRILINEAR DIAGRAM - WILD HORSE CREEK SURFACE WATER AND GROUNDWATER QUALITY VALUES

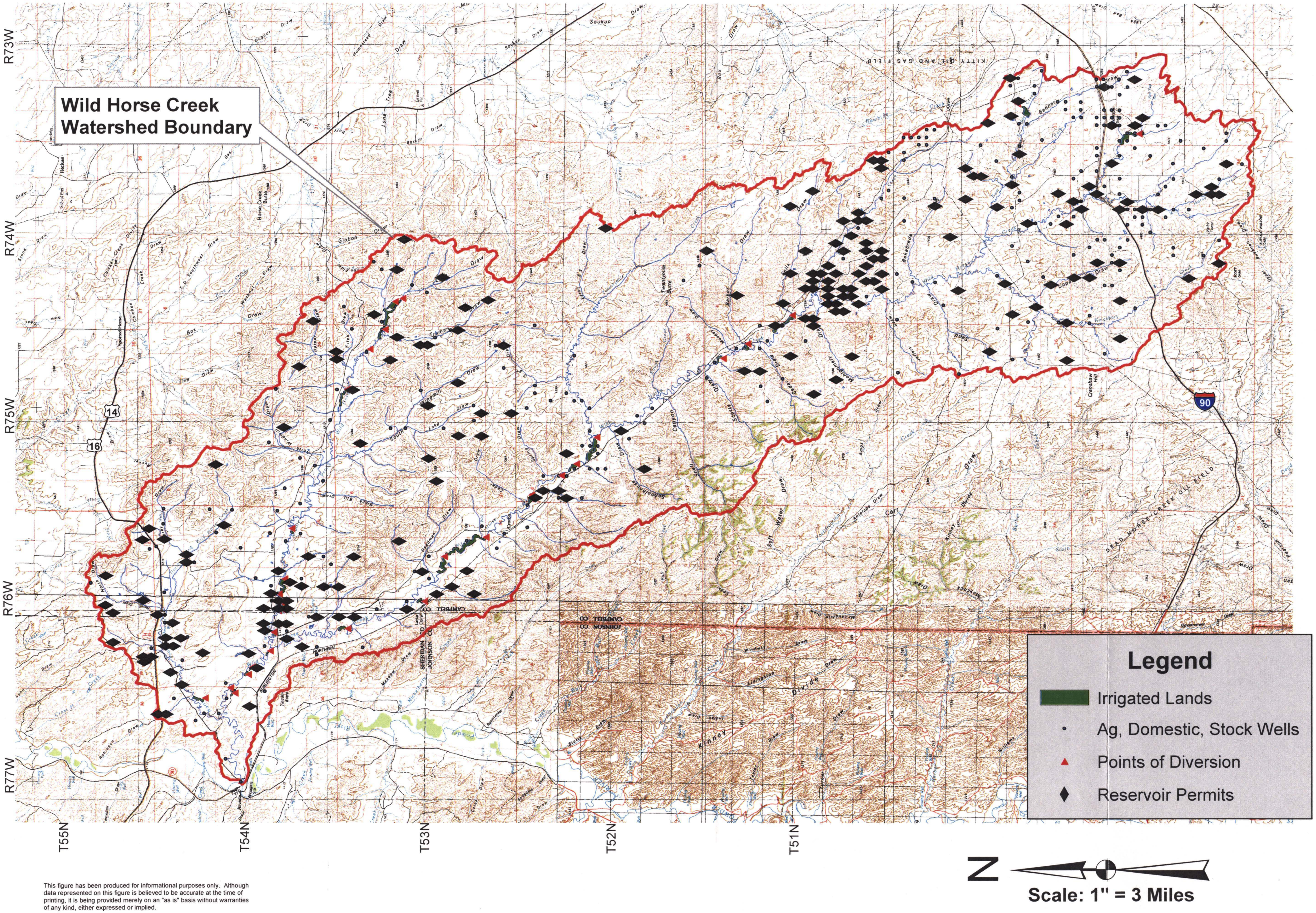
FIG. 2.2.4

Runoff Samples
- 1 USGS
- 2 USGS
- 3 USGS
- 4 USGS
- 5 USGS
- 6 WH−1
- 7 WH−2

Shallow Groundwater Samples
- 8 Wasatch
- 9 Wasatch
- A Wasatch
- B Wasatch
- C Wasatch
- D Wasatch
- E Wasatch
- F Wasatch

Coal Bed Samples
- G Anderson
- H Anderson
- I Anderson
- J Fort Union
- K Fort Union
- L Fort Union





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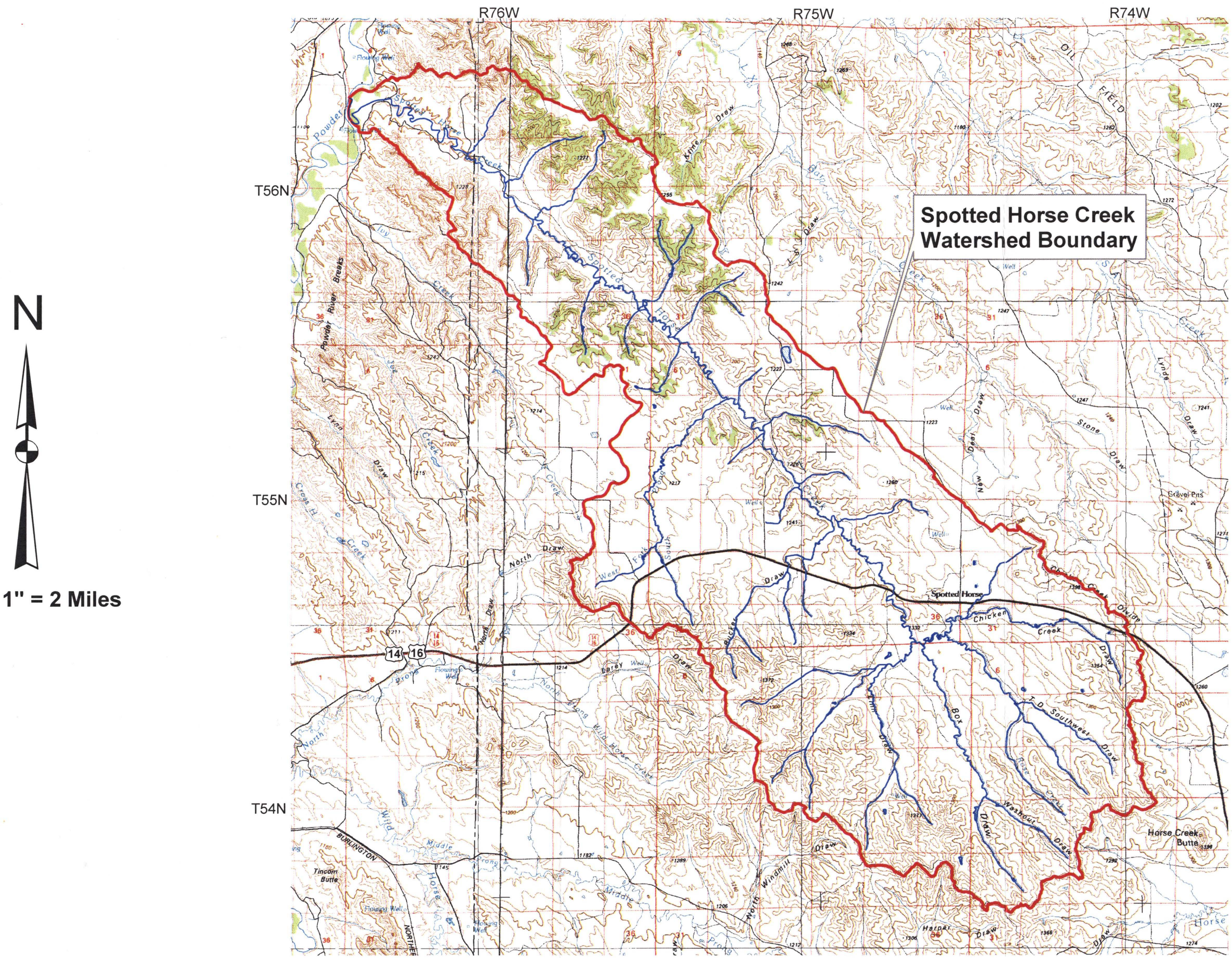
WILD HORSE CREEK WATERSHED SURFACE WATER AND GROUNDWATER USE

THREE HORSES WATERSHED PLAN LEVEL I STUDY

EnTech, Inc.
Consulting Engineers
Transportation - Municipal - Environmental - Water Resources
1949 Sugarland Drive, Suite 205
Sheridan, Wyoming 82801
Phone 307-673-1542
Fax 307-673-1547
E-mail entech@entechusa.net

FIG. 2.2.5



Scale: 1" = 2 Miles

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DATE DEC 02
PROJECT NO. 01006

SPOTTED HORSE CREEK WATERSHED BOUNDARY

THREE HORSES WATERSHED PLAN LEVEL I STUDY

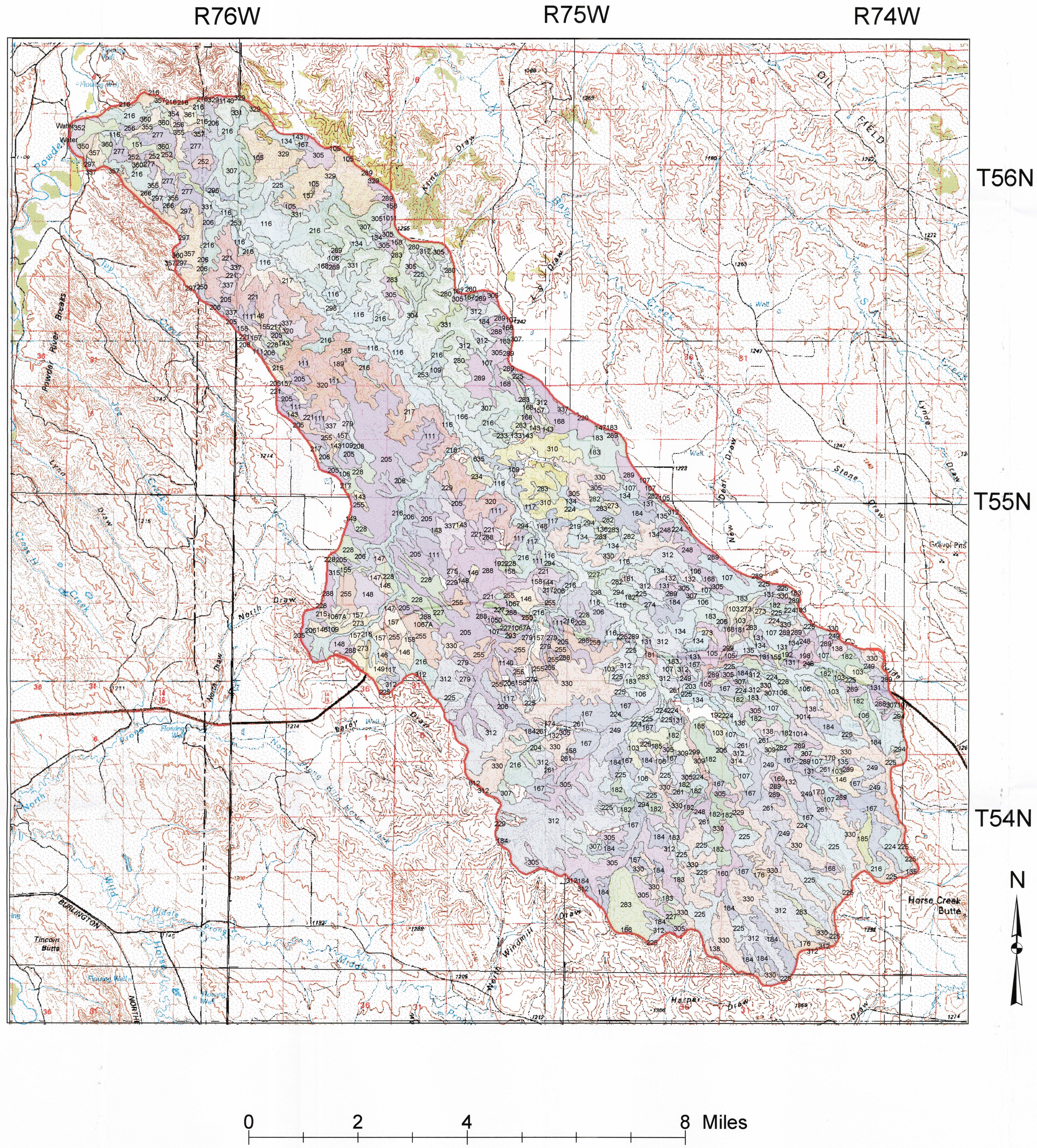
EnTech, Inc.
Consulting Engineers
Transportation - Municipal - Environmental - Water Resources
1949 Sugarland Drive, Suite 205
Sheridan, Wyoming 82801
Phone 307-673-1542
Fax 307-673-1547
E-mail entech@entechusa.net

FIG. 2.3.1

Spotted Horse Creek Watershed
Soil and Range Site Map Legend

Map Symbol	Soil - Range Site Name
101	Arvada, thick surface, very fine sandy loam, 0 to 6 percent slopes – Loamy 10-14” np
103	Arwite sandy loam, 0 to 6 percent slopes – Sandy 15-17” np
105	Arwite-Elwop sandy loams, 0 to 6 percent slopes – Sandy 15-17” np
106	Arwite-Elwop sandy loams, 6 to 15 percent slopes – Sandy 15-17” np
107	Arwite-Vonalf sandy loams, 0 to 6 percent slopes – Sandy 15-17” np
109	Bidman loam, 0 to 6 percent slopes – Loamy 10-14” np
111	Bidman-Parmleed loams, 0 to 6 percent slopes – Loamy 10-14” np
114	Bowbac-Taluce-Badlands complex, 3 to 20 percent slopes –Sandy 10-14” np
116	Cambria-Kishona-Zigweid loams, 0 to 6 percent slopes – Loamy 10-14” np
117	Cambria-Kishona-Zigweid loams, 6 to 15 percent slopes –Loamy 10-14” np
131	Deekay loam, 0 to 6 percent slopes –Loamy 15-17” np
132	Deekay-Moorhead loams, 0 to 6 percent slopes – Loamy 15-17” np
133	Deekay-Moorhead loams, 6 to 15 percent slopes – Loamy 15-17” np
134	Deekay-Oldwolf loams, 0 to 6 percent slopes – Loamy 15-17” np
135	Deekay-Oldwolf loams, 6 to 15 percent slopes – Loamy 15-17” np
136	Deekay-Ziggy loams, 0 to 6 percent slopes – Loamy 15-17” np
138	Echeta-Cromack clay loams, 6 to 15 percent slopes – Clayey 15-17” np
143	Felix clay, ponded, 0 to 2 percent slopes – Clayey Overflow 15-17” np
144	Forkwood loam, 0 to 6 percent slopes – Loamy 10-14” np
146	Forkwood-Cushman loams, o to 6 percent slopes – Loamy 10-14” np
147	Forkwood-Cushman loams, 6 to 15 percent slopes – Loamy 10-14” np
148	Forkwood-Ulm loams, 0 to 6 percent slopes – Loamy 10-14” np
149	Forkwood-Ulm loams, 6 to 15 percent slopes – Loamy 10-14” np
154	Held clay loam, 0 to 6 percent slopes – Clayey 10-14” np
155	Heldt-Bidman complex, saline, 0 to 3 percent slopes – Saline Upland/Loamy 10-14” np
157	Hiland-Bowbac sandy loams, 0 to 6 percent slopes – Sandy 10-14” np
158	Hiland-Bowbac sandy loams, 6 to 15 percent slopes – Sandy 10-14” np
160	Hiland-Vonalee sandy loams, 6 to 15 percent slopes – Sandy 10-14” np
166	Jaywest loam, 0 to 6 percent slopes – Loamy 15-17” np
167	Jaywest-Moorhead loams, 0 to 6 percent slopes – Loamy 15-17” np
168	Jaywest-Spottedhorse loams, 0 to 6 percent slopes – Loamy 15-17” np
169	Julesburg sandy loam, 0 to 6 percent slopes – Sandy 15-17” np
170	Keeline-Tullock loamy sands, 6 to 30 percent slopes – Sandy 10-14” np
171	Keeline-Tullock-Niobrara, dry, complex, 3 to 30 percent slopes – Sandy/Shallow Sandy 10-14” np
174	Brislawn-Rockybutte-Ironbutte complex, 0 to 10 percent slopes – Loamy 10-14” np
176	Leiter-Cromack clay loams, 3 to 15 percent slopes – Clayey 15-17” np
181	Moorhead clay loam, 0 to 6 percent slopes – Clayey 15-17” np
182	Moorhead loam, 0 to 6 percent slopes – Loamy 15-17” np
183	Moorhead-Leiter clay loams, 0 to 6 percent slopes – Clayey 15-17” np
184	Moorhead-Leiter clay loams, 6 to 15 percent slopes – Clayey 15-17” np
185	Moskee fine sandy loam, 0 to 6 percent slopes – Sandy 15-17” np
189	Oshoto- Moorhead loams, 0 to 6 percent slopes – Loamy 15-17” np
192	Platmak loam, 0 to 6 percent slopes – Loamy 15-17” np
198	Recluse loam, 0 to 6 percent slopes – Loamy 15-17” np
201	Renohill-Shingle-Worf complex, 3 to 15 percent slopes – Clayey/Shallow Loamy 10-14” np
203	Rockypoint-Iwait association, 0 to 6 percent slopes – Lowland/Loamy 15-17” np
204	Samday-Samday Cool-Shingle clay loams, 6 to 40 percent slopes – Shallow Clayey/Very shallow 10-14” np
205	Samday-Savageton clay loams, 3 to 15 percent slopes – Clayey/Shallow Clayey 10-14” np
206	Samday-Shingle-Badlands complex, 10 to 45 percent slopes – Shallow Clayey/Shallow Loamy 10-14” np
208	Savageton-Silhouette clay loams, 0 to 6 percent slopes – clayey 10-14” np
215	Theedle-Kishona loams, 6 to 20 percent slopes – Loamy 10-15” np
216	Theedle-Kishona-Shingle loams, 3 to 30 percent slopes - Loamy 10-14” np
217	Theedle-Shingle loams, 3 to 30 percent slopes – Loamy/Shallow Loamy 10-14” np
220	Pitchdraw-Ashollow-Niobrara complex, 3 to 30 percent slopes – Sandy 15-17” np
221	Turnercrest-Keeline-Taluce sandy loams, 6 to 30 percent slopes – Sandy 10-14” np
224	Ucross-Iwait loams, 0 to 6 percent slopes – Loamy 15-17” np
225	Ucross-Iwait-Fairburn loams, 3 to 30 percent slopes - Loamy 15-17” np
227	Ulm clay loam, 0 to 6 percent slopes – Clayey 10-14” np
228	Ulm-Renohill clay loams, 0 to 6 percent slopes – Clayey 10-14” np
229	Ulm-Renohill clay loams, 6 to 15 percent slopes – Clayey 10-14” np
233	Ustic Torriorthents, gullied - Unspecified
234	Ustic Torriorthents-Badlands complex, 10 to 100 percent slopes - Unspeciified
236	Vonalee-Terro sandy loams, 2 to 10 percent slopes – Sandy 10-14” np
248	Ziggy-Iwait loams, 0 to 6 percent slopes – Loamy 15-17” np
249	Ziggy-Iwait loams, 6 to 15 percent slopes – Loamy 15-17” np
250	Ziggy-Ucross-Oldwolf loams, 3 to 15 percent slopes – Loamy 15-17” np
251	Water
252	Absted-Slickspots complex, 0 to 6 percent slopes – Saline Upland 10-14” np
253	Absted-Arvada-Slickspots complex, 0 to 6 percent slopes – Saline Upland 10-14” np
255	Ulm-Bidman complex, 0 to 6 percent slopes – Clayey/Loamy 15-17” np
260	Foreleft-bonfri loams, 3 to 15 percent slopes – Loamy 15-17” np
261	Echeta-Moorhead clay loams, ponded, 0 to 2 percent slopes – Clayey 15-17” np
266	Jaywest-jaywest stratified substratum, loams, 0 to 6 percent slopes – Loamy 15-17”np
268	Pinehill-Pylon loams, 3 to 15 percent slopes – Loamy 15-17” np
273	Nuncho clay loam, 0 to 6 percent slopes – Clayey 15-17” np
274	Oldwolf-Fairburn loams, 3 to 15 percent slopes – Loamy/shallow Loamy 15-17” np
275	Oshoto-Ziggy silt loams, 0 to 6 percent slopes – Loamy 15-17” np
277	Parmleed-Bidman association, 3 to 15 percent slopes – Loamy 10-14” np
279	Silhouette-Ulm clay loams, 0 to 6 percent slopes – clayey 15-17” np
280	Spottedhorse-Leiter complex, 0 to 6 percent slopes – Loamy/Clayey 15-17” np
282	Ucross-Fairburn loams, 3 to 15 percent slopes – Loamy/Shallow Loamy 15-17” np
283	Ucross-Fairburn loams, 15 to 45 percent slopes – Loamy/Shallow Loamy 15-17” np
288	Vonalee-Terro-Taluce fine sandy loams, 3 to 30 percent slopes – Sandy 10-14” np
289	Vonalf-Xema-Mittenbutte fine sandy loams, 3 to 30 percent slopes – Sandy 15-17” np
293	Muleherder-Ironbutte complex, range, 10 to 60 percent slopes – Shallow Loamy 15-17” np
294	Wibaux-Shingle-Taluce complex, 6 to 40 percent slopes – Shallow Loamy 10-14” np
296	Zigweid-Cambria loams, 0 to 6 percent slopes – Loamy 15-17” np
298	Haverdad-Boruff complex, 0 to 6 percent slopes – Lowland 10-14” np
299	Rockypoint-Boruff complex, 0 to 6 percent slopes – Lowland 15-17” np
304	Haverdad clay loam, 0 to 3 percent slopes – Lowland 10-14” np
305	Cromack-Samsil clay loams, 3 to 15 percent slopes – Clayey/Shallow Clayey 15-17” np
307	Fairburn-Mittenbutte-Badlands complex, 6 to 45 percent slopes – Shallow Loamy/Shallow/Clayey 15-17” np
309	Cedarbutte-Slickspots complex, 0 to 6 percent slopes – Loamy/Saline 15-17” np3
310	Ironbutte-Faiurburn-Mittenbutte complex, wooded, 6 to 40 percent slopes – Woodland Suitability Group
312	Fairburn-Samsil-Badlands complex, 6 to 45 percent slopes – Shallow Loamy/Shallow Clayey 15-17” np
313	Cabbart-Yawdim-Badlands complex, 6 to 45 percent slopes – Shallow Loamy/Shallow Clayey 15-17” np
314	Pitchdraw-Ashollow-Mittenbutte fine sandy loams, 3 to 30 percent slopes – Sandy 15-17” np
315	Hiland-Vonalee fine sandy loams, 0 to 6 percent slopes – Sandy 10-14” np
317	Lismas-Sabatka-Xema complex, 3 to 25 percent slopes – Shallow Clayey/Clayey 15-17” np
320	Shingle-Taluce-Badlands complex, wooded, 3 to 25 percent slopes – Ponderosa Pine/Little Bluestem
329	Elwop-Mittenbutte-Badlands complex, wooded, 3 to 60 percent slopes - Woodland Suitability Group
330	Ironbutte-Fairburn-Mittenbutte complex, range, 6 to 40 percent slopes – Shallow Loamy 15-17” np
331	Fairburn-Mittenbutte-Badland complex, wooded, 3 to 45 percent slopes – Woodland Suitability Group
337	Oshoto-Klinedraw silt loams, 0 to 6 percent slopes – Loamy 15-17” np
350	Abstad-Haverdad association, 0 to 6 percent slopes – Loamy 10-14” np
351	Bidman-Arvada fine sandy loams, 0 to 6 percent slopes – Loamy 10-14” np
352	Haverdad-Draknab complex, 0 to 3 percent slopes – Lowland 10-14” np
353	Haverdad-Worthenton complex, 0to 3 percent slopes – Lowland/Wetland
354	Renohill-Ulm, dry, 3 to 15 percent slopes – Clayey 10-14” np
355	Shingle-Haverdad association, 0 to 80 percent slopes – Shallow Loamy/Overflow 10-14” np
356	Shingle-Nihill complex, 3 to 80 percent slopes – Shallow Loamy 10-14” np
357	Shingle-Rock Outcrop complex, 30 to 50 percent slopes – Shallow Loamy 10-14” np
358	Shingle-Samday clay loams, 6 to 60 percent slopes – Shallow Loamy 10-14” np
359	Taluce-Tullock-vonalee association, 6 to 15 percent slopes – Shallow Sandy/Sandy 10-14” np
360	Worfka-Shingle-Samday complex, 6 to 30 percent slopes – Shallow Loamy 10-14” np
361	Wyarno clay loam, dry, 3 to 6 percent slopes – Clayey 10-14” np
362	Wyarno clay loam, 6 to 9 percent slopes – clayey 10-14” np
363	Forkwood loam, 6 to 9 percent slopes – Loamy 10-14” np
364	Kishona-Cambria complex, 3 to 6 percent slopes – Loamy 10-14” np
365	Parmaleed-Renohill complex, moist, 3 to 9 percent slopes – Loamy/Clayey 10-14” np
366	Parmaleed-renohill complex, 9 to 25 percent slopes – Loamy/Clayey 10-14” np
367	Parmaleed-Worfka association, 0 to 15 percent slopes – Loamy 10-14” np
368	Reget silt loam, 0 to 6 percent slopes – Clayey 15-17” np
369	Searing-Ringling association, 2 to 75 percent slopes – Loamy/Shallow Loamy 15-17” np
370	Shingle-Samday clay loams, moist, 3 to 55 percent slopes – Shallow Loamy/Shallow Clayey 15-17” np
371	Shingle-Theedle complex, 45 to 75 percent slopes, Shallow Loamy/Loamy 10-14” np
372	Shingle-Worf complex, 6 to 15 percent slopes – Shallow Loamy 10-14” np
373	Taluce-Tullock-Vonalee association, moist, 9 to 30 percent slopes – Shallow Sandy/Sandy 15-17” np
374	Twin Creek Variant silt loam, 0 to 3 percent slopes - Subirrigated

Note: 4-digit numbers are unidentified and are treated here as miscellaneous soils
Some polygons may be missing a number and are treated as miscellaneous soils



Digitizing and GIS Mapwork conducted by
EDE Consultants
Environmental Engineering * Hydrology * Water Resources Engineering
23 N. Scott, Suite 23 Sheridan, WY (307) 672-3793

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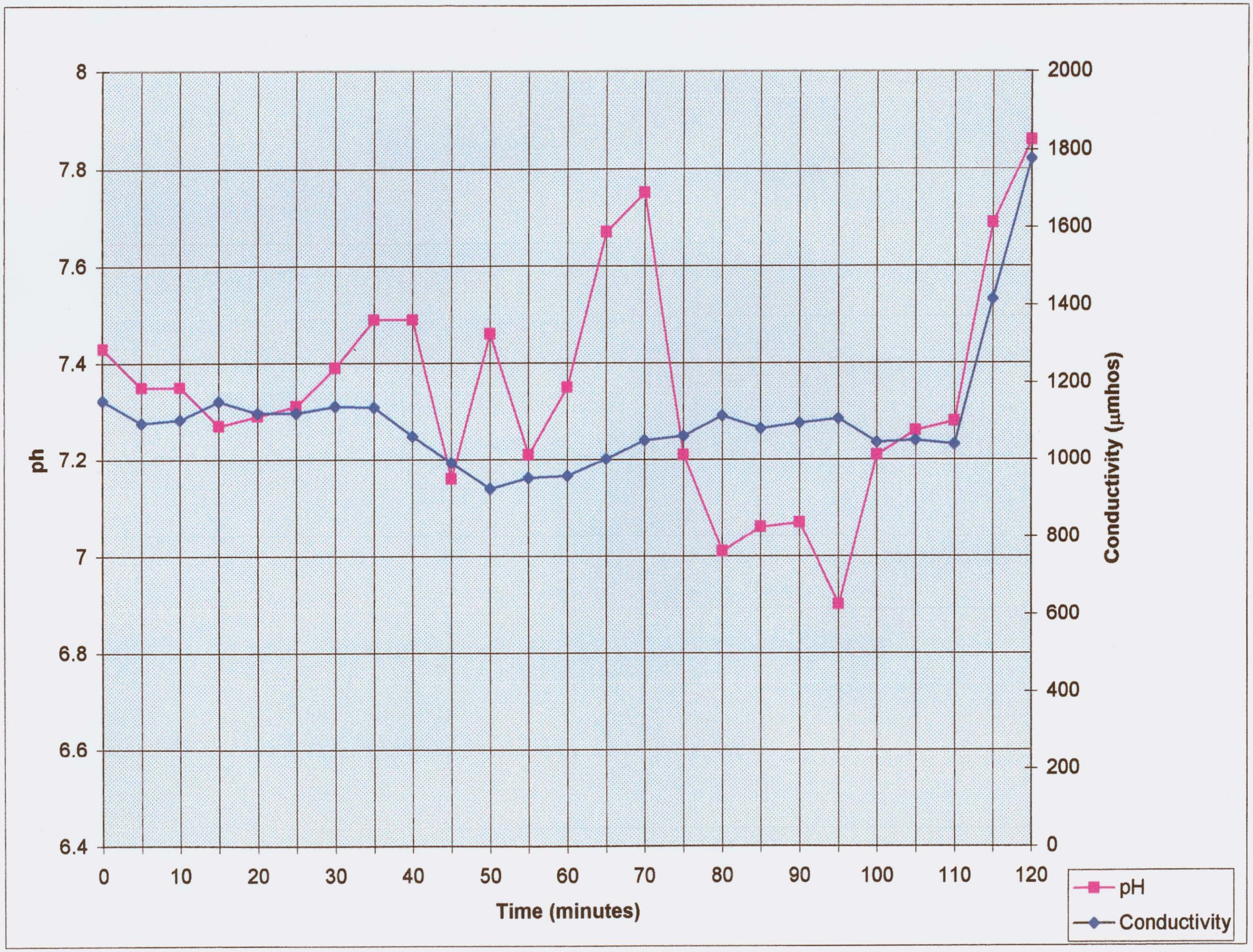
PROJECT NO. 01006

SPOTTED HORSE CREEK
WATERSHED SOILS

THREE HORSES
WATERSHED MASTER PLAN
WWDC LEVEL I STUDY

EnTech, Inc.
Consulting Engineers
Transportation Municipal Environmental Water Resources
1949 Sugarland Drive, Suite 205
Sheridan, Wyoming 82801
Phone 307-673-1542
Fax 307-673-1547
E-mail entech@entechusa.net

FIG. 2.3.2



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Consulting Engineers
Transportation • Municipal • Environmental • Water Resources
1949 Sugarland Drive, Suite 205
Sheridan, Wyoming 82801
Phone 307-673-1542
Fax 307-673-1547
E-mail entech@entechusa.net

SPOTTED HORSE CREEK SURFACE WATER SAMPLES - JULY 23 AND 24, 2001

FIG. 2.3.3

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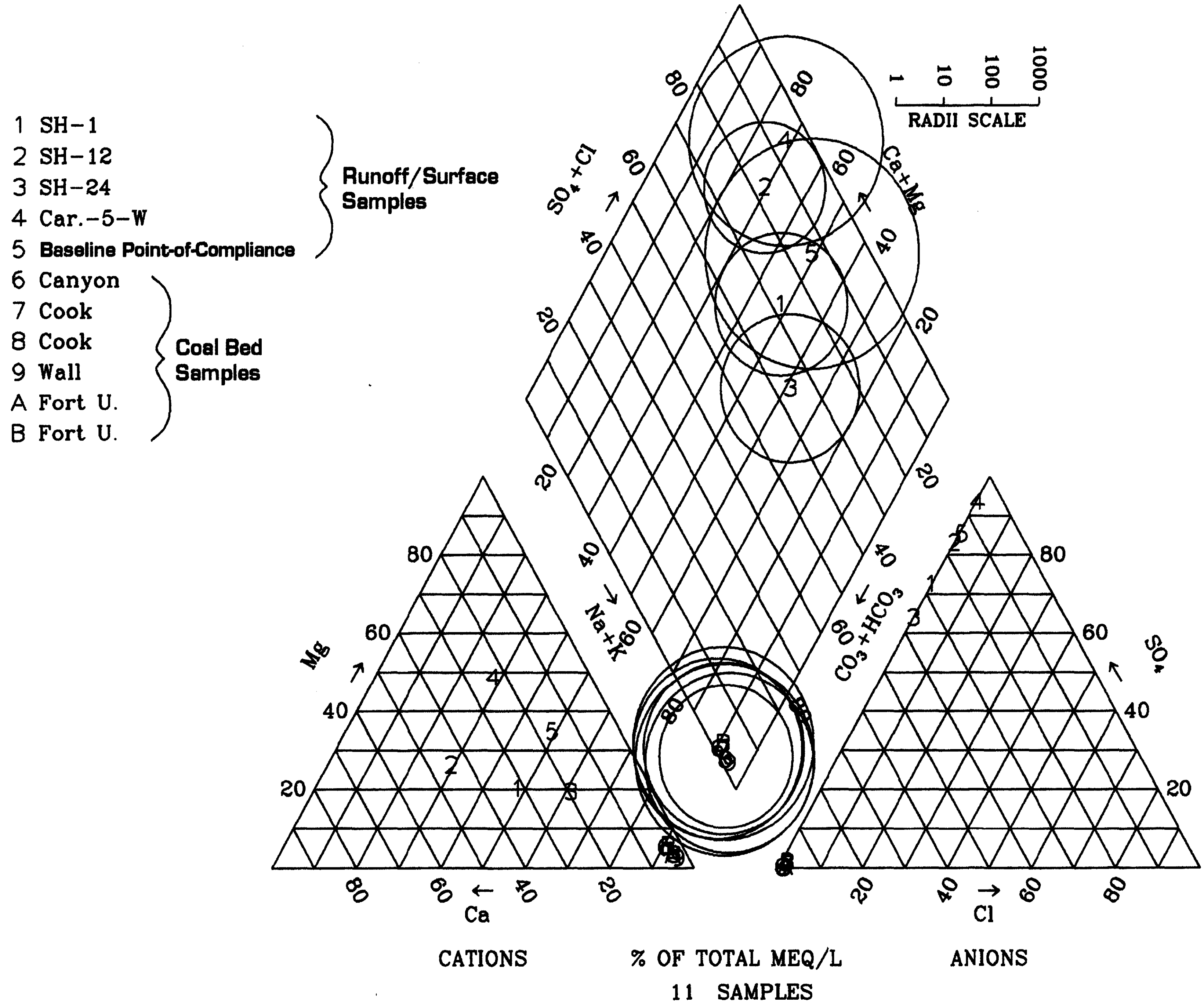
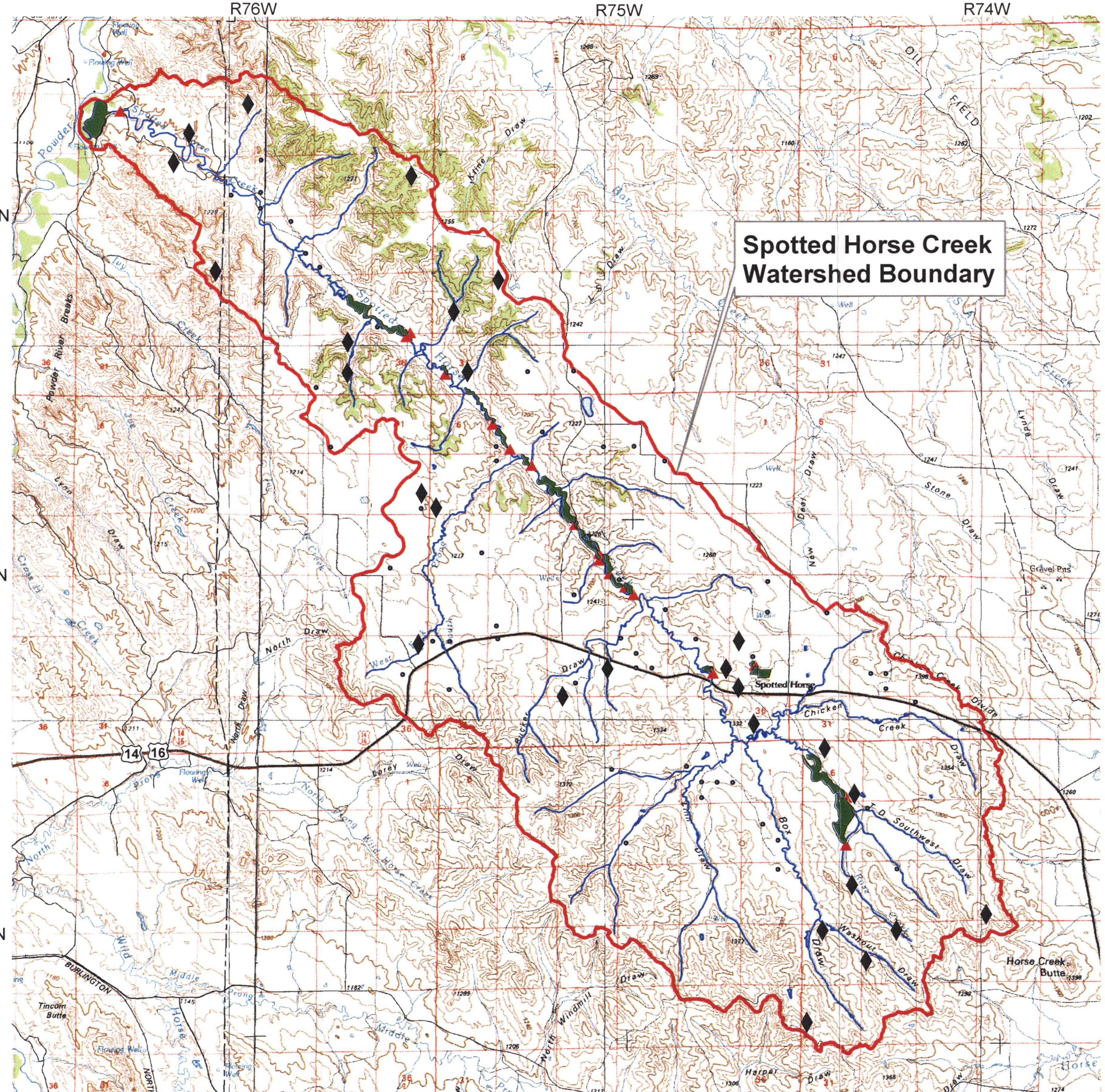


TRILINEAR DIAGRAM - SPOTTED HORSE CREEK SURFACE AND GROUNDWATER QUALITY VALUES

FIG. 2.3.4



N

Scale: 1" = 2 Miles

Legend

- Irrigated Lands
- Ag, Domestic, Stock Wells
- Points of Diversion
- Reservoir Permits

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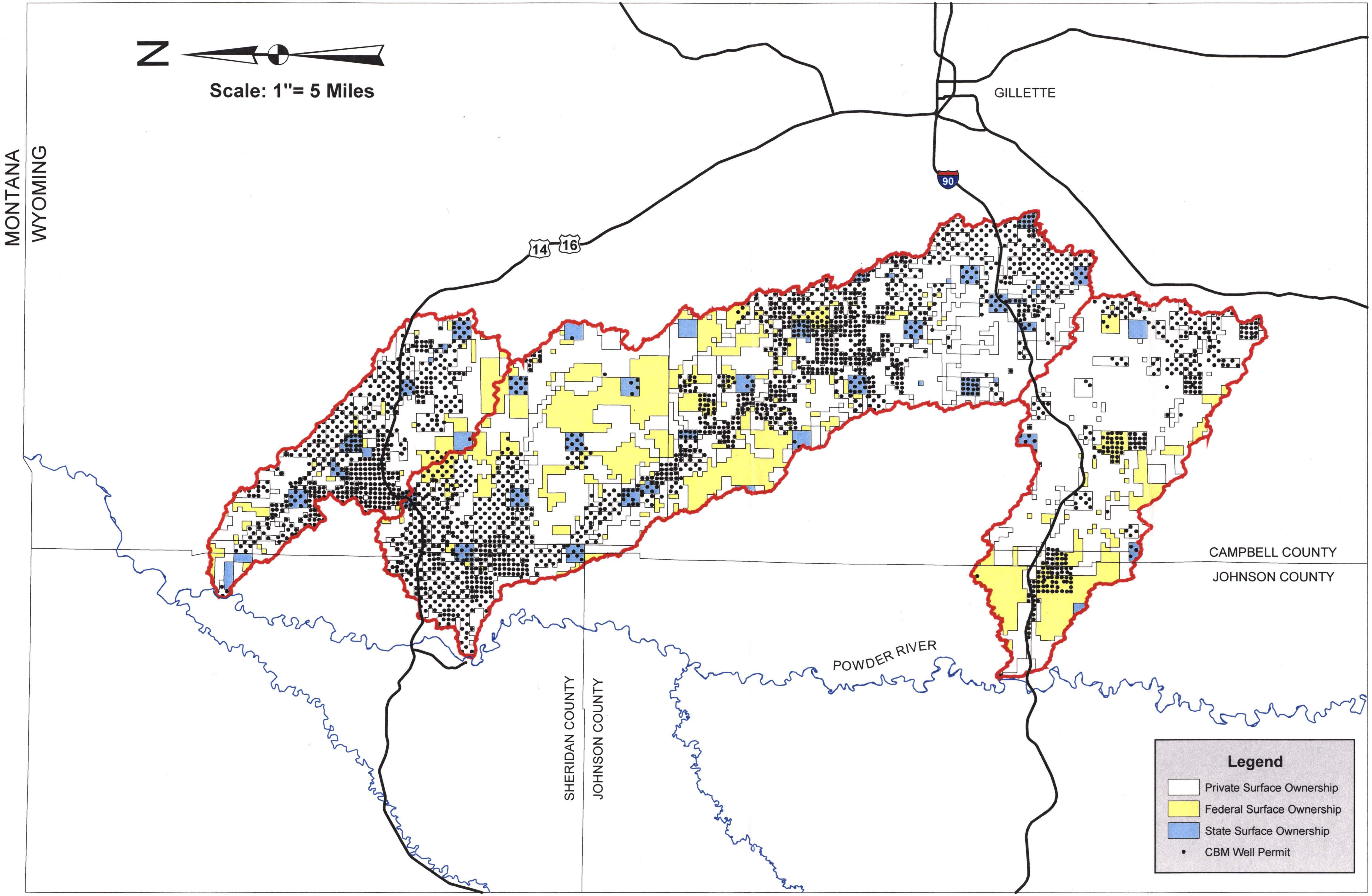
SPOTTED HORSE CREEK WATERSHED SURFACE WATER AND GROUNDWATER USE

THREE HORSES WATERSHED PLAN LEVEL I STUDY

EnTech, Inc.
Consulting Engineers
Transportation - Municipal - Environmental - Water Resources
1949 Sugarland Drive, Suite 205
Sheridan, Wyoming 82801
Phone 307-673-1542
Fax 307-673-1547
E-mail entech@entechusa.net

FIG. 2.3.5



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CBM WELL PERMITS IN THE THREE HORSES WATERSHEDS

THREE HORSES WATERSHED PLAN LEVEL I STUDY

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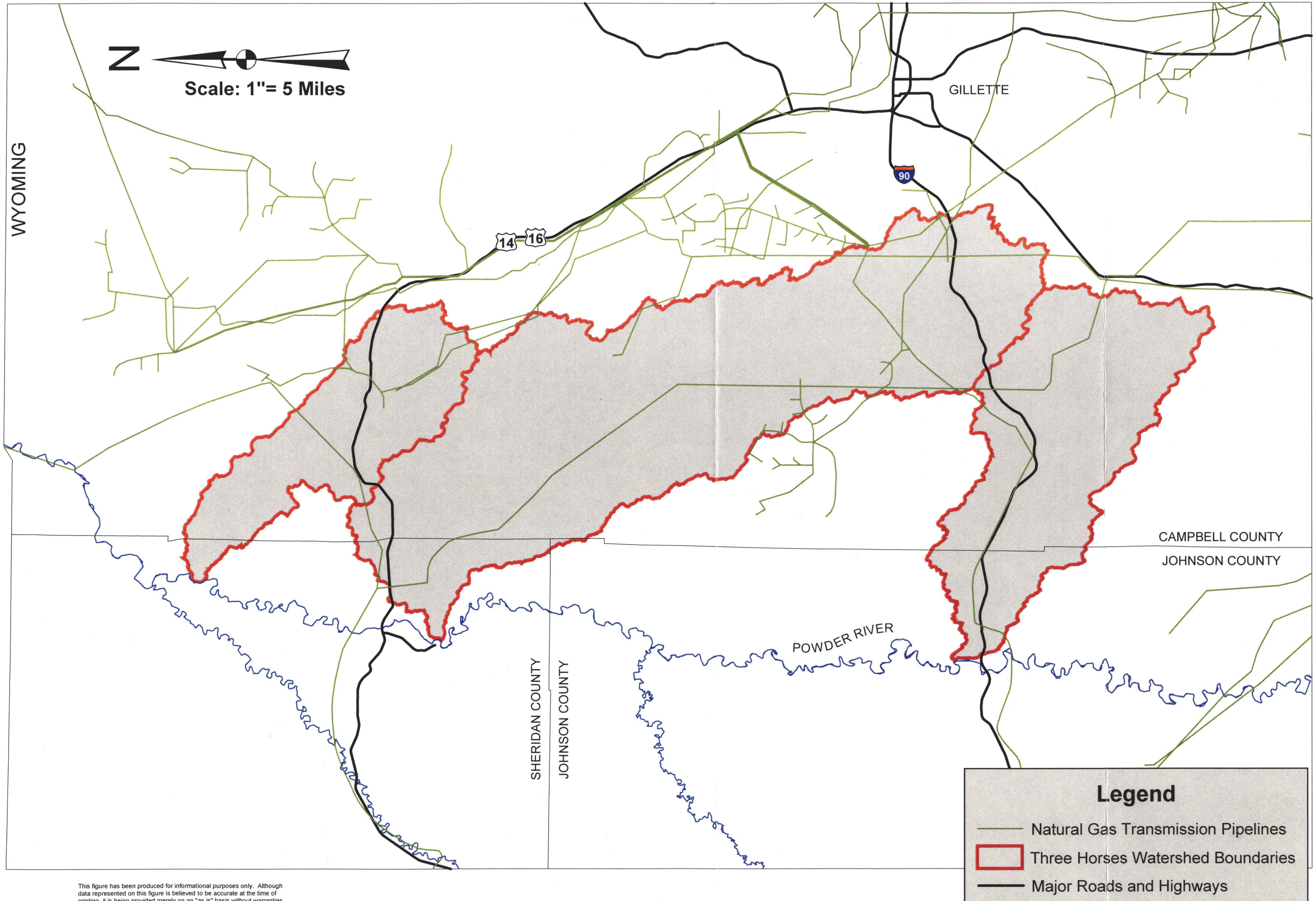
Transportation - Municipal - Environmental - Water Resources
1949 Sugarland Drive, Suite 205
Sheridan, Wyoming 82801
Phone 307-673-1542
Fax 307-673-1547
E-mail entech@entechusa.net

FIG. 3.1



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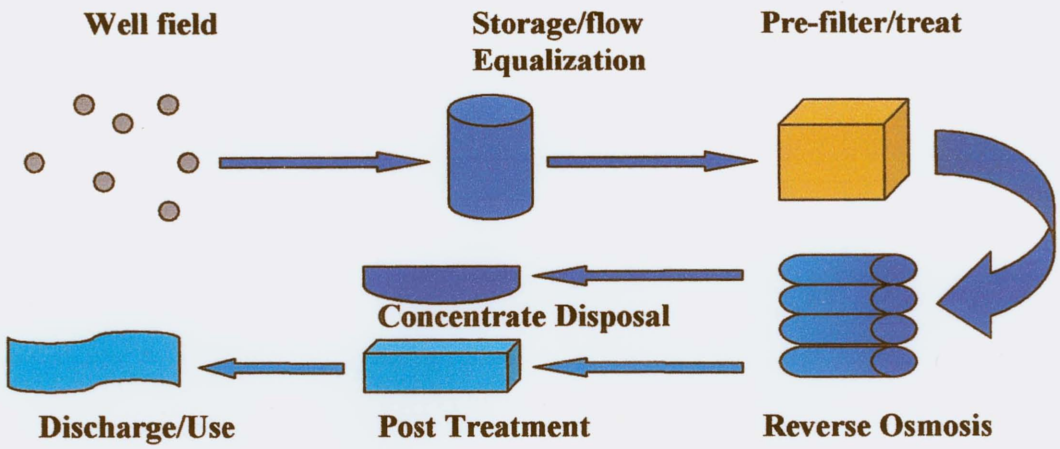
THREE HORSES WATERSHEDS
NATURAL GAS
TRANSMISSION PIPELINES

THREE HORSES
WATERSHED PLAN
LEVEL I STUDY

EnTech, Inc.
Consulting Engineers
Transportation - Municipal - Environmental - Water Resources
1949 Sugarland Drive, Suite 205
Sheridan, Wyoming 82801
Phone 307-673-1542
Fax 307-673-1547
E-mail entech@entechusa.net

FIG. 3.2



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Fax 307-673-1547
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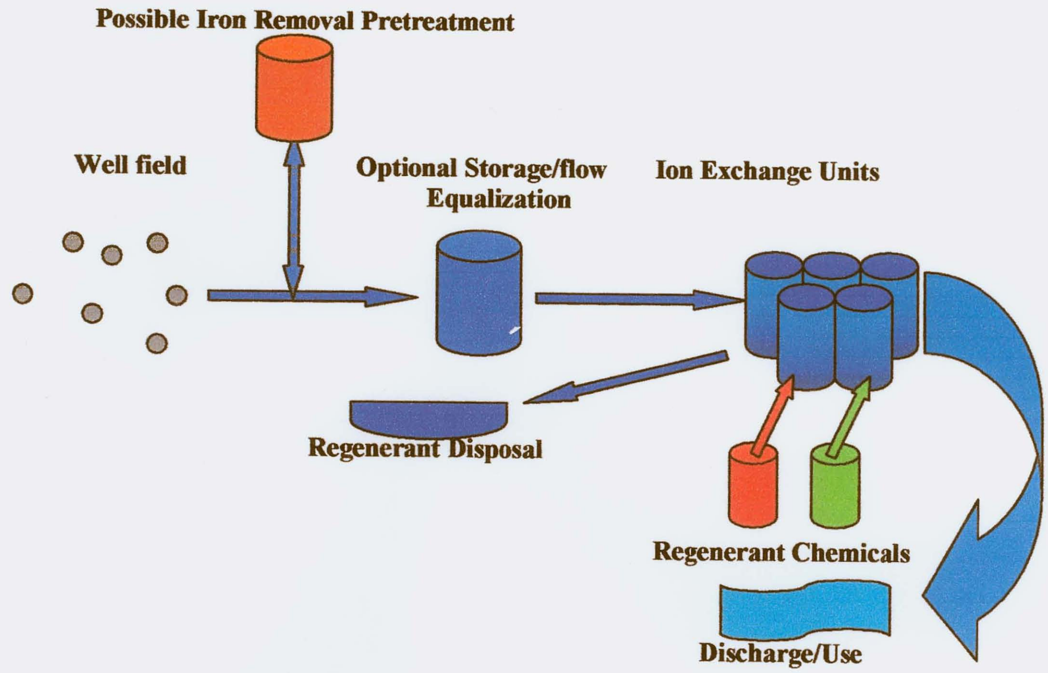
TYPICAL WATER TREATMENT PROCESS FOR REVERSE OSMOSIS

FIG. 4.10.1



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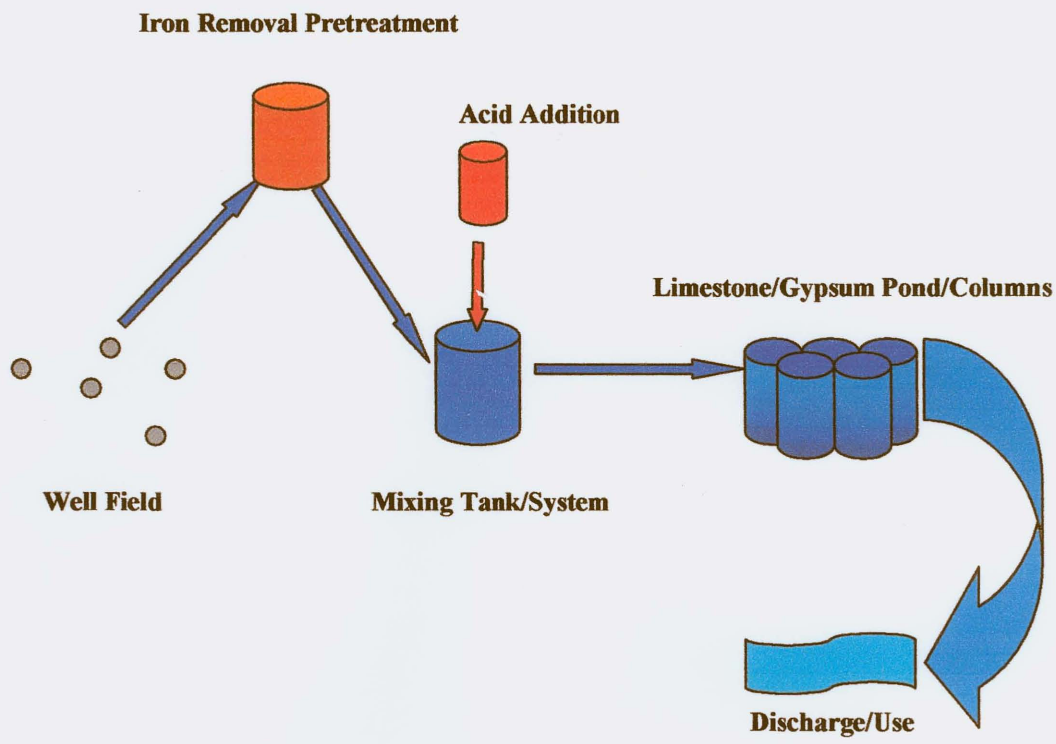
Consulting Engineers
Transportation · Municipal · Environmental · Water Resources
1949 Sugarland Drive, Suite 205
Sheridan, Wyoming 82801
Phone 307-673-1542
Fax 307-673-1547
E-mail entech@entechusa.net

TYPICAL WATER TREATMENT PROCESS
FOR ION EXCHANGE

FIG. 4.11.1



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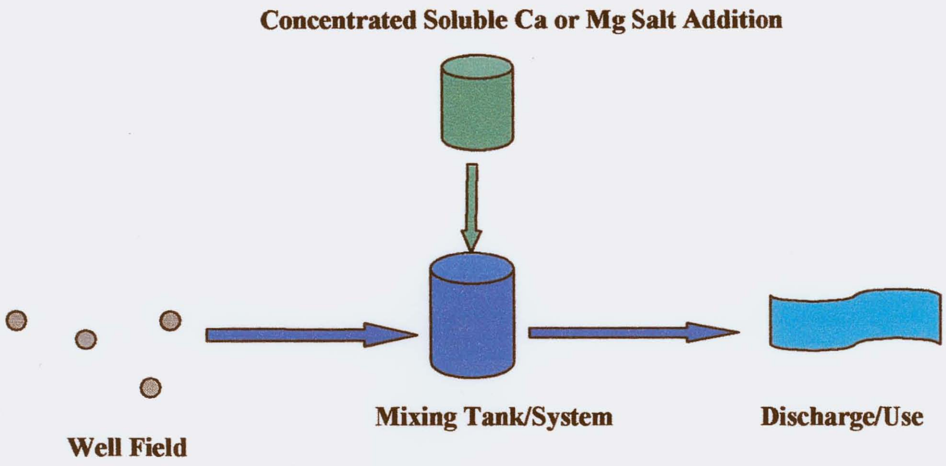
Consulting Engineers
Transportation·Municipal·Environmental·Water Resources
1949 Sugarland Drive, Suite 205
Sheridan, Wyoming 82801
Phone 307-673-1542
Fax 307-673-1547
E-mail entech@entechusa.net

TYPICAL WATER TREATMENT PROCESS FOR ION RATIO MODIFICATION, SOLID FEED SYSTEM

FIG. 4.12.1



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Consulting Engineers
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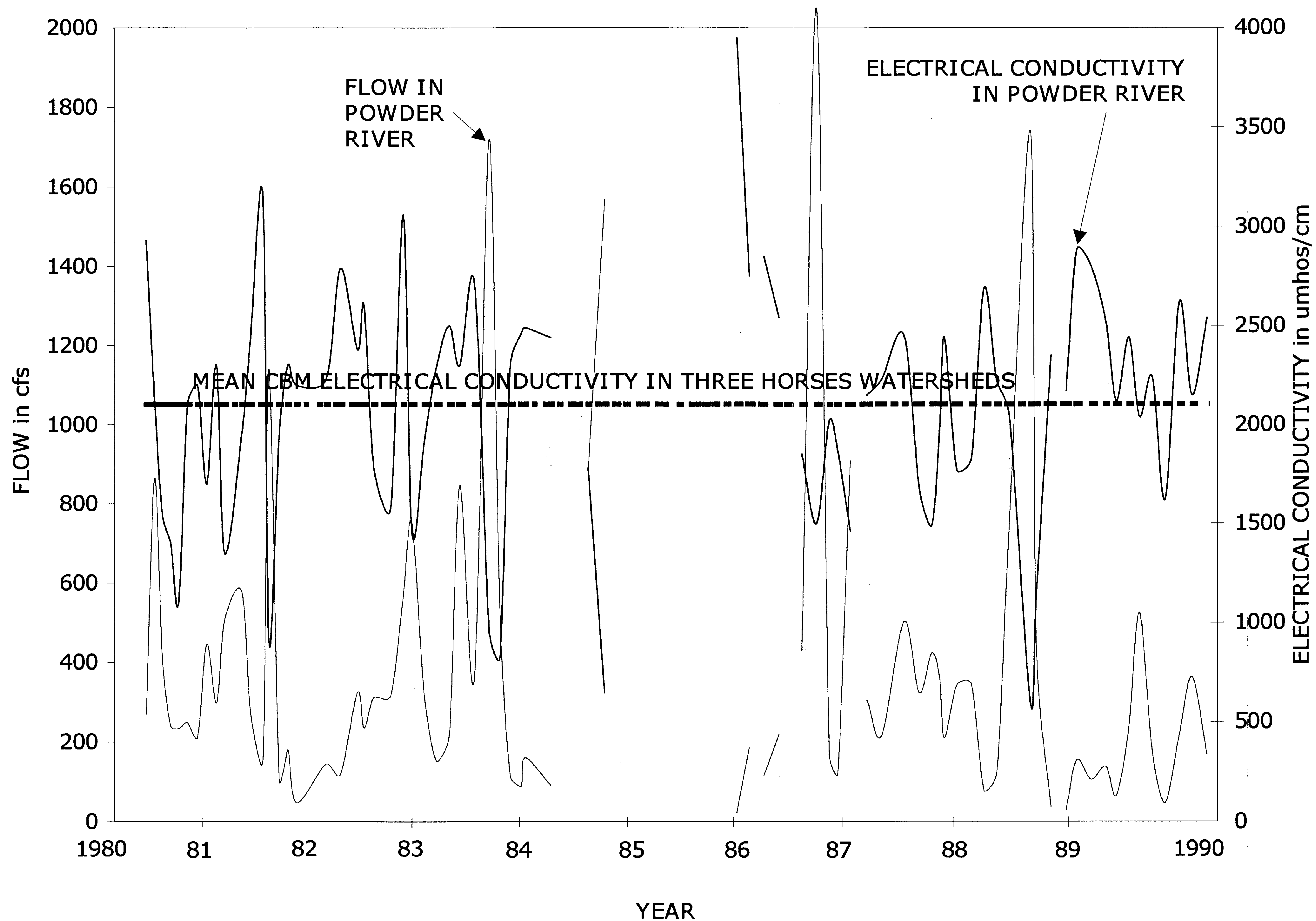
1949 Sugarland Drive, Suite 205
Sheridan, Wyoming 82801
Phone 307-673-1542
Fax 307-673-1547
E-mail entech@entechusa.net

TYPICAL WATER TREATMENT PROCESS FOR ION RATIO MODIFICATION, LIQUID FEED SYSTEM

FIG. 4.12.2



ELECTRICAL CONDUCTIVITY LEVELS IN POWDER RIVER AT MOORHEAD, MT GAGING STATION

THREE HORSES WATERSHED PLAN LEVEL I STUDY

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Sheridan, Wyoming 82801
Phone 307-673-1542
Fax 307-673-1547
E-mail entech@entechusa.net

Fig. 4.13.1

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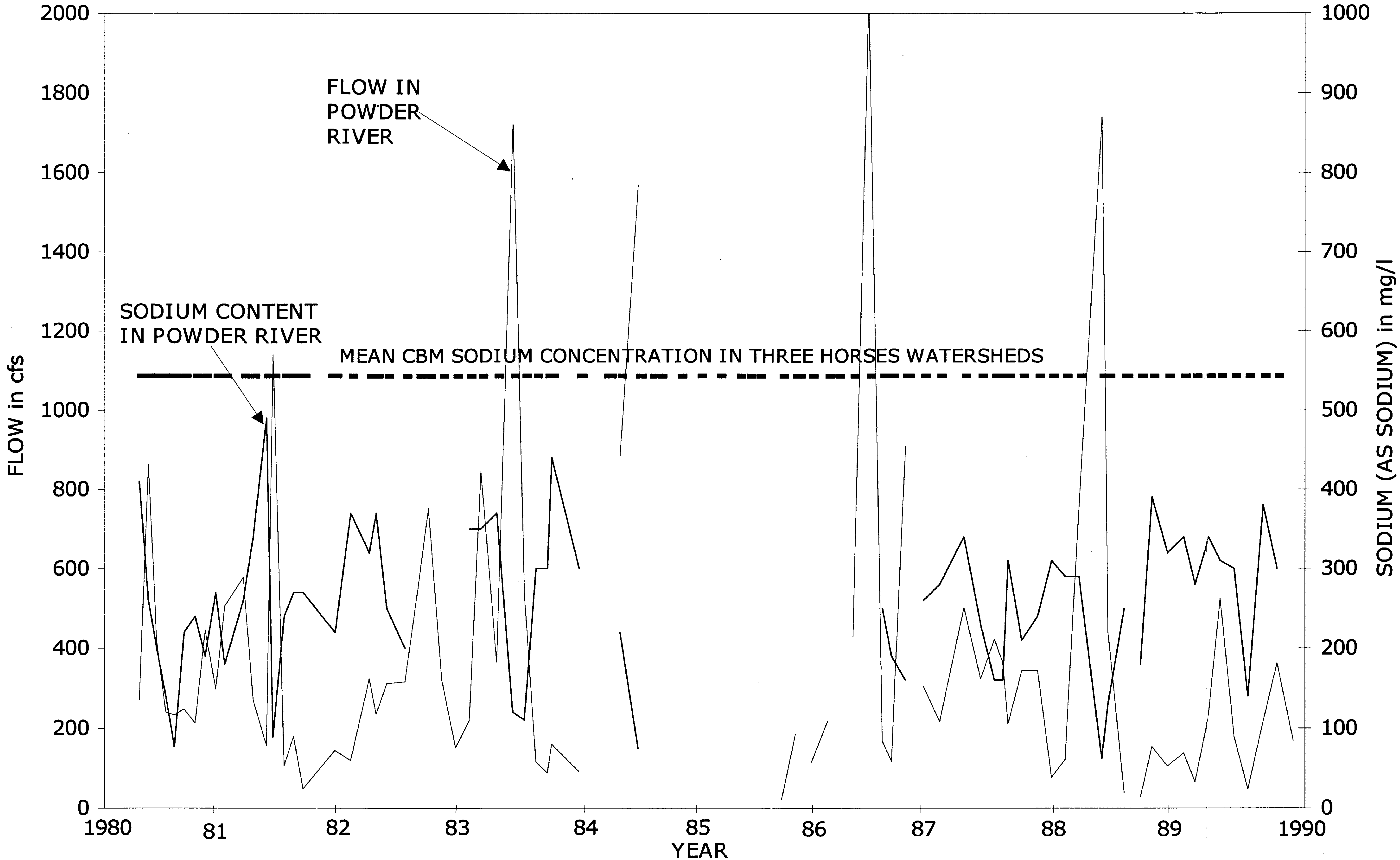

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SODIUM LEVELS IN POWDER RIVER AT MOORHEAD, MT GAGING STATION

THREE HORSES WATERSHED PLAN LEVEL I STUDY

EnTech, Inc.
Consulting Engineers
Transportation · Municipal · Environmental · Water Resources
1949 Sugarland Drive, Suite 205
Sheridan, Wyoming 82801
Phone 307-673-1542
Fax 307-673-1547
E-mail entech@entechusa.net

Fig. 4.13.2

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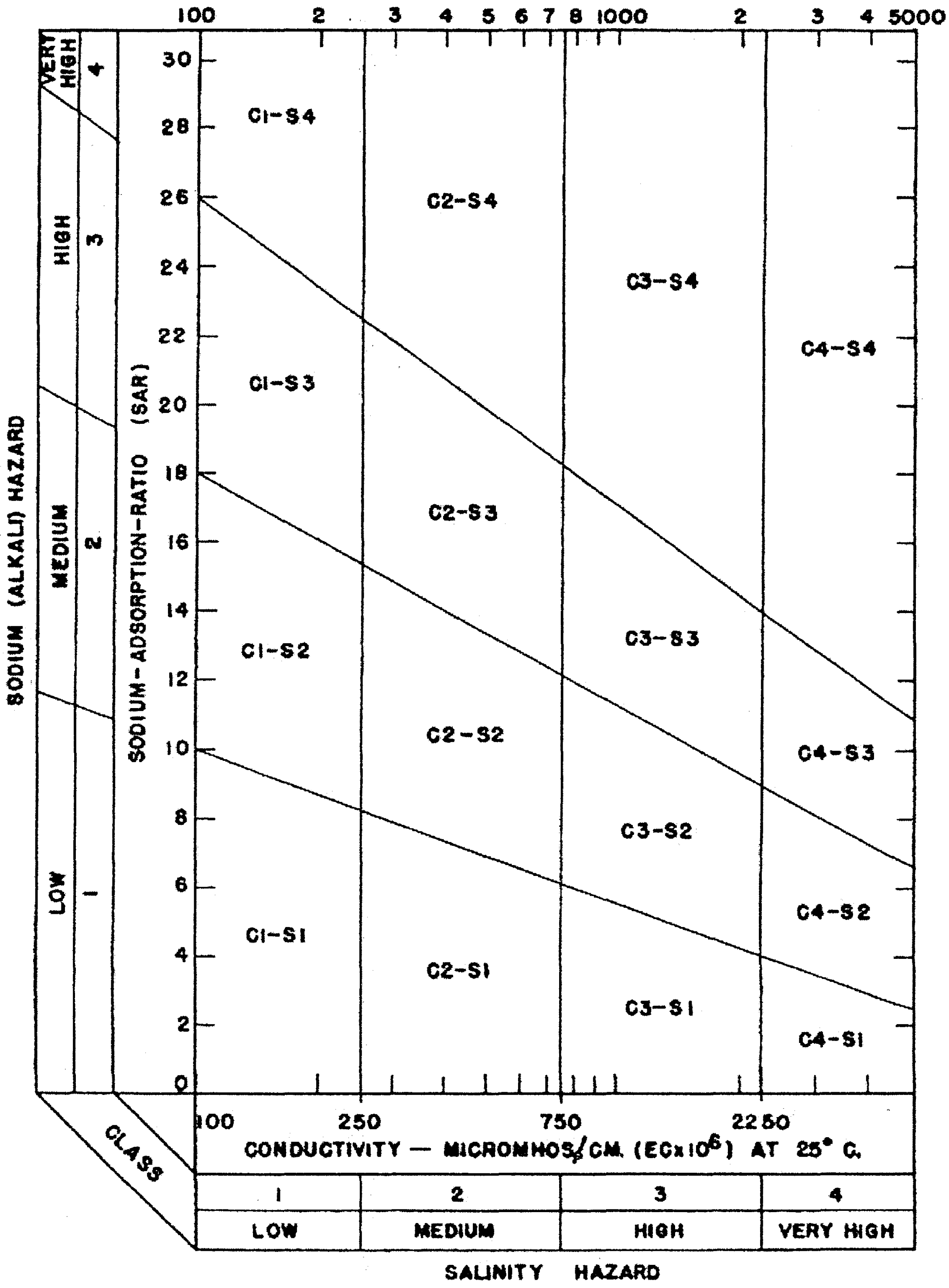

FIGURE 25.—Diagram for the classification of irrigation waters.

EnTech, Inc.
Consulting Engineers
Transportation · Municipal · Environmental · Water Resources
1949 Sugarland Drive, Suite 205
Sheridan, Wyoming 82801
Phone 307-673-1542
Fax 307-673-1547
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USDA HANDBOOK NO. 60,
FIGURE 25

FIG. 4.16.1

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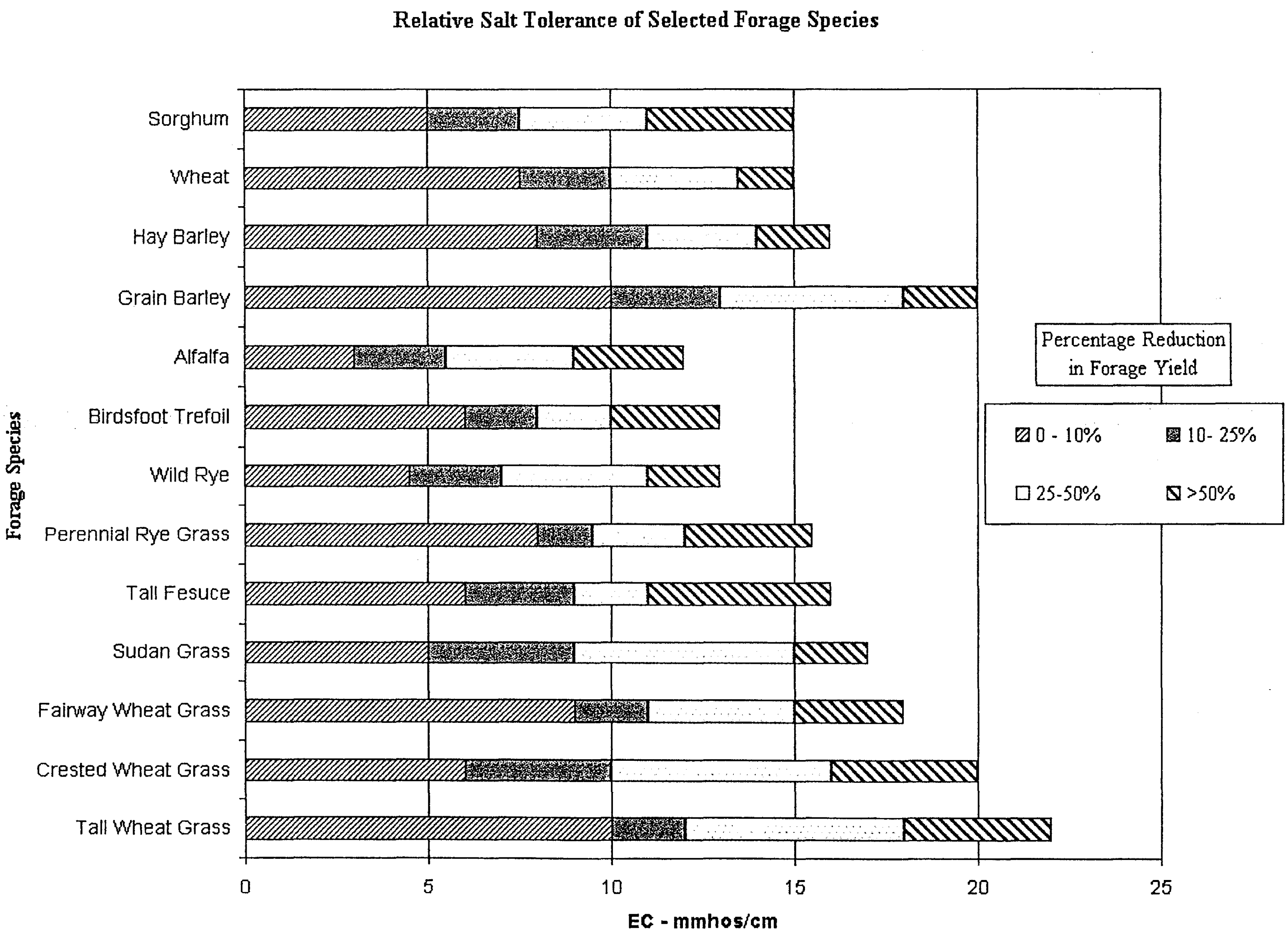
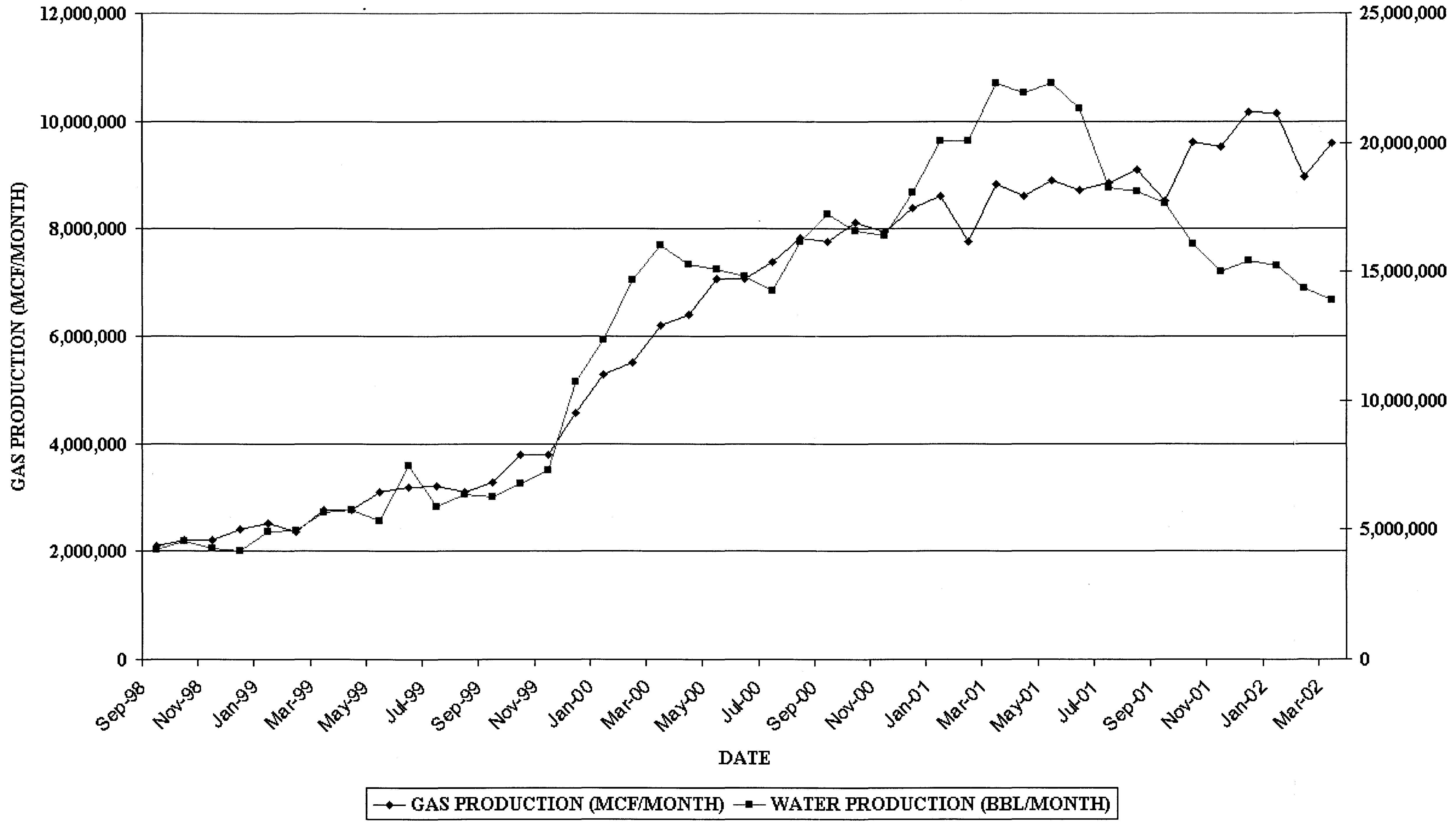


RELATIVE SALT TOLERANCE OF SELECTED FORAGE SPECIES

FIG. 4.16.2

BELLE FOURCHE RIVER DRAINAGE
GAS AND WATER PRODUCTION



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BELLE FOURCHE RIVER GAS AND WATER PRODUCTION WITH TIME

THREE HORSES WATERSHED PLAN LEVEL I STUDY

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Fig. 5.1

APPENDIX 1

(on CD-ROM)

GIS MAPPING
NRCS DESCRIPTIONS OF SOIL MAPPING UNITS