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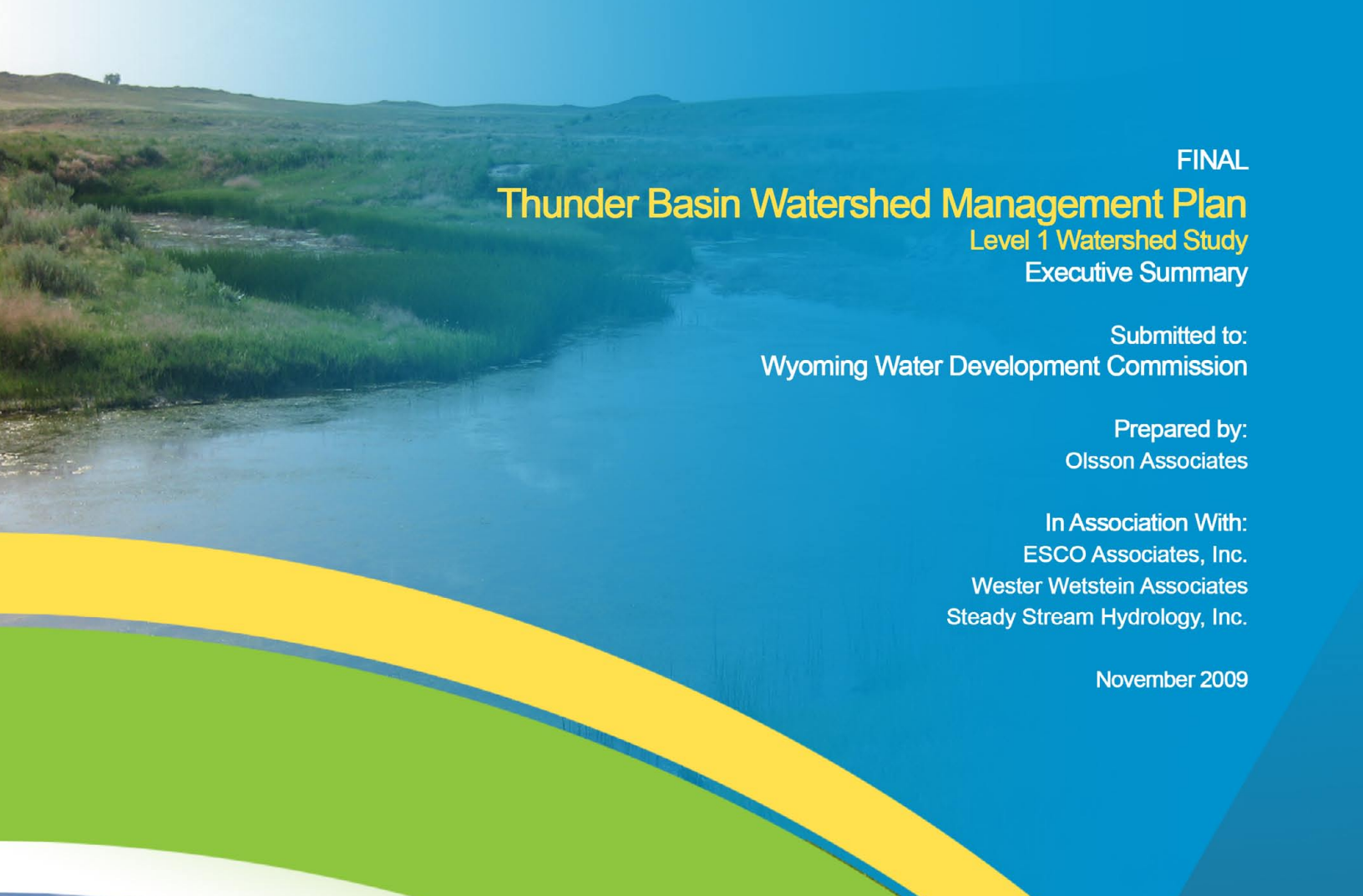

FINAL

Thunder Basin Watershed Management Plan

Level 1 Watershed Study

Executive Summary

Submitted to:
Wyoming Water Development Commission

Prepared by:
Olsson Associates

In Association With:
ESCO Associates, Inc.
Wester Wetstein Associates
Steady Stream Hydrology, Inc.

November 2009

OLSSON ASSOCIATES

Olsson Project No. 008-1217

EXECUTIVE SUMMARY

Thunder Basin Watershed Management Plan

Level I Watershed Study

WWDC Contract Number 055C0293618

November 30, 2009

I hereby certify that this report was prepared by us or under our direct supervision and that we are duly Licensed Professional Geologists and Engineers under the laws of the State of Wyoming.

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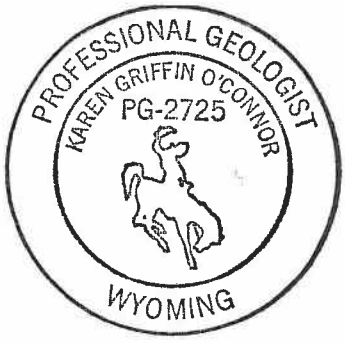

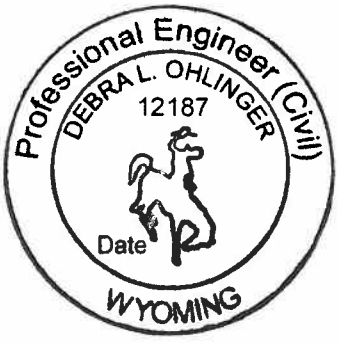

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ES-1.0 Introduction

Olsson Associates (Olsson) prepared the Thunder Basin Watershed Management Plan for the Wyoming Water Development Commission in accordance with Contract No. 055C0293618. The plan was prepared in association with ESCO Associates (ESCO) of Boulder, Colorado, Steady Stream Inc. of Sheridan, Wyoming and Wester Westein & Associates (WWA) of Laramie, Wyoming. The plan was prepared on behalf of the watershed landowners and the project sponsors including the Thunder Basin Grazing Association (TBGA), the Thunder Basin Grasslands Prairie Ecosystem Association and the four conservation districts that are represented in the Thunder Basin Watershed (Converse, Campbell, Weston and Niobrara).

ES-1.1 Purpose and Scope

The purpose of this Watershed Management Plan is to describe Thunder Basin watershed in its current condition and to suggest resolutions for any water related issues and opportunities identified. Level I watershed studies include an extensive inventory and description of the watershed with scientific information on geology, hydrology, soils, climate, plant communities, wildlife habitat, infrastructure, and the geomorphic characteristics of the watershed stream system. The information gathered is intended to be used to develop proposed watershed improvements. Specific to this study, the project sponsors requested an evaluation of surface and groundwater availability, the potential to develop upland livestock and wildlife water resources, and the potential to develop and enhance additional irrigation systems and water storage. Proposed projects are listed in the report and include cost estimates as well as information on project financing opportunities and project permitting considerations.

ES-1.2 Overview of Study Area Key Issues

Thunder Basin watershed lies in the northeast portion of Wyoming and includes the Upper Cheyenne River, Dry Fork Cheyenne River, and Antelope Creek which are the primary tributaries to the Cheyenne River System. The watershed is located in northeast Converse, southeast Campbell, southwest Weston and northwest Niobrara counties (Figure ES-F1, Study Area Location). The watershed encompasses approximately 1.9 million acres of primarily grassland. The area has a robust livestock industry and is one of the world's largest producers of coal. Since early 2000, however, the area has been abnormally dry and the drought conditions have exacerbated the need for additional water development and distribution.

The TBGA in conjunction with the four conservation districts (Converse, Campbell, Weston, and Niobrara), the BLM, NRCS, WWDC and other government agencies, have been promoting watershed improvement projects and best management practices across the area. With the extended drought conditions and the prospect of additional project support through the WWDC, the TBGA and the conservation districts decided to promote the completion of this Level 1 study in order to provide a comprehensive, multidisciplinary watershed management plan that will identify and begin to address the key issues facing the area. The intent was to produce a watershed management plan that would take into account the landowners' requests for future project improvements and also provide a comprehensive understanding of the current conditions of the watershed so that projects that will benefit a multitude of landowners and recreational visitors could be coordinated across the area.

In order to solicit landowner involvement and input, this project began with a series of bimonthly project meetings where information was solicited on specific project initiatives including irrigation system upgrades, upland water development (wells), surface water storage, stream, and rangeland enhancements.

Approximately 20 percent of the landowners across Thunder Basin responded to the request for information. Seven landowners had no specific projects for evaluation; however, they asked to be kept informed of the project status. Two of the landowners had ranches outside of the watershed boundary and were not evaluated as part of this project. Of the remaining 10 responses, six requested irrigation system evaluations, eight requested information on well development opportunities, four requested information on water storage sites and six were interested in stream and rangeland enhancements. Landowners that requested evaluation and granted site access were visited by the project team. Specific issues raised at project meetings during the site visits and in written responses included:

- *Irrigation Systems* – Less than 1 percent of Thunder Basin is irrigated and spreader dike systems are used as the standard for water distribution throughout Thunder Basin. There were several requests to upgrade spreader dike systems.
- *Groundwater Well Development* – Additional stock and wildlife water supplies are needed throughout the basin to enhance range conditions and habitat restoration. Solar wells were requested with pipelines, as needed, to reduce the distance cattle must travel to water.
- *Water Storage Sites* – The majority of landowners are not interested in medium to large reservoirs, however, most are interested in small stock watering ponds that can supply water to an area consistently throughout the year.
- *Stream Erosion* – There are specific areas along Black Thunder Creek, Cheyenne River and Owl Creek where stream erosion is an issue.
- *Rangeland/Riparian Conservation* – Questions arose about what grasses would perform best in specific soil types with minimal precipitation. Also, the riparian areas along the Cheyenne River and Black Thunder Creek were mentioned with questions raised about what is causing the large number of dead cottonwoods.

With these specific key issues identified, the project team began a comprehensive evaluation of the watershed.

ES-2.0 Conclusions and Recommendations

This section provides a summary of the conclusions and recommendations presented throughout this report. The conclusions pertain to the watershed inventory and current conditions of the watershed. The recommendations include the proposed watershed improvements projects, environmental permitting and financing.

ES-2.1 Conclusions

Natural Environment

Thunder Basin watershed lies within the geologic structural basin called the Powder River Basin, which is part of the Missouri Plateau of the Great Plains. Thunder Basin watershed consists of a dissected, rolling upland plain with low to moderate relief, broken by buttes, mesas, hills, and ridges. The present-day landforms of the semiarid region have been shaped mostly by the action of water, even though precipitation is low and evaporation greatly exceeds precipitation. Erosion-resistant clinker, produced by the natural burning of coal beds, caps many hills and ridges within Thunder Basin with a characteristic broken, red brick colored rock. The drainages dissecting Thunder Basin are incised, typically are ephemeral or intermittent, and do not naturally provide permanent or year-round sources of water along the entirety of their reaches. Augmenting surface precipitation runoff are springs and seeps that are fed by groundwater from shallow aquifers.

Climate **-** The climate of the Thunder Basin watershed can be classified as semiarid with average annual rainfall of 14 inches. Since 2000, the watershed has experienced drought conditions as exemplified by the 2008 U.S Drought Monitor map that identified the southern portion of the watershed as affected by drought conditions. Of the10 weather stations that used to monitor the Thunder Basin Watershed, only one in Dull Center is still operational. At Dull Center, the average annual precipitation is 12.8 inches per year.

Vegetation and Land Cover **-** The bulk of upland vegetation in Thunder Basin is comprised of plant communities in which grasses are predominant, biologically, and visually. In addition, especially in the uplands of the north-central, south central and far west portions the grass component is joined by a substantial presence of big sagebrush. Vegetational components that have particular importance with respect to the water resources and watershed function of Thunder Basin include the Russian olive, salt cedar, and noxious weeds such as Canada thistle.

- Salt cedar is capable of establishing, far from known occurrences, in areas with only the slightest moisture accumulation. Salt cedar is established in the Cow Creek and Red Hills areas and has recently begun to appear on Antelope Creek and the Cheyenne River, as well as certain tributaries.
- Establishment of young Russian olive on Antelope Creek and the Cheyenne River has been particularly heavy. If allowed to proceed, new establishment of stands of Russian olive and salt cedar can produce dense thickets. This will, in turn, increase depletion of massive amounts of shallow groundwater (with direct connection to surface water). Besides the loss of water, the dense thickets can be expected to shade out and out-compete previously existing riparian species, including the native cottonwoods and willows.
- Other noxious weeds are present in the study area and the most abundant is Canada thistle. To the extent that any of these noxious weeds displace diverse native plant communities to form extensive monocultures, they may not only diminish livestock and wildlife forage values, but they may negatively influence watershed function.

Soils **-** A comprehensive soil survey was completed by the NRCS across the entire Thunder Basin. Soils within the Thunder Basin watershed have developed in residual material and alluvium in a climatic regime characterized by cold winters, warm summers, and low-to-moderate precipitation. Soils in the Thunder Basin watershed are generally low in organic matter and are alkaline. Textures range from clay loams to sandy loams with varying amounts of gravel or coarser materials. Slopes range from nearly level to very steep with deeper soils found in the less steeply sloping areas. These soils support little crop agriculture except in irrigated valleys of perennial streams. Across Thunder Basin the predominant land use is rangeland. Vegetation developed on the soils is predominantly grass-shrub, used for grazing and wildlife habitat.

Geology **-** Surficial and bedrock deposits across the watershed are divided into three distinct types: 1) Bedrock, residuum and mined areas; 2) River Valley Deposits; and, 3) Upland Deposits. The four shallow bedrock units that directly underlie the surficial deposits, or are exposed in isolated outcrops and along ridges/slopes of Thunder Basin have played an important role in soil formation and other geomorphologic processes. The four shallow bedrock units from youngest to oldest include:

- Tertiary Wasatch Formation
- Tertiary Fort Union Formation; Lebo member

- Tertiary Fort Union Formation; Tullock member
- Cretaceous Lance Formation

Most of the surficial geologic material across Thunder Basin watershed is described as residuum with eolian and alluvium. The residuum deposits are composed of fine clay, silt, and sand ranging up to coarse sands and gravels. The river valley deposits are significant to the watershed study because they represent a significant source of surface and groundwater. The upland deposits include eolian deposits with scattered alluvium. Slopewash with colluvium is mapped along the steeper slopes in the western portion of the watershed.

Landslides **-** Small, localized, slope failures can occur along the banks of active channels. Slope instability increases during times of material saturation accompanying storm events when undercutting of stream banks is most intense. For this reason, watershed improvement projects should include site-specific geologic hazard analyses, including an evaluation of the site's susceptibility to landslides.

Groundwater **-** Groundwater in Thunder Basin occurs in both alluvial (shallow) and bedrock (deeper) aquifers. Alluvial aquifers occur in the stream-valley alluvium located along rivers and major drainages. The alluvial aquifers are generally less than 50 feet in thickness but can be as thick as 100 feet in some valleys west of Thunder Basin. The alluvial aquifers yield 5-10 gpm on average with some isolated occurrences of higher production. The bedrock aquifers are part of the Northern Great Plains aquifer system and in Thunder Basin, the aquifer system includes the Tertiary aquifers exposed at the surface, as well as the deeper regional aquifers within older sedimentary rocks deposited during the Upper and Lower Cretaceous and Paleozoic. Bedrock wells can produce up to 500 gpm. Springs occur where the groundwater table intersects the ground surface. Springs occur across Thunder Basin but are abundant along exposures of clinker deposits.

Surface Water Hydrology **-** Within the Thunder Basin Watershed, there is only one active (and six historic) USGS streamflow gaging stations. Most of the gages show the majority of flow occurring between March and August with peaks generally occurring in May and March. With this sparse dataset and information developed for the Northeast Wyoming River Basins Plan Final Report, water availability and shortages as related to proposed water storage projects in the Thunder Basin study area were evaluated. The following reaches within Thunder Basin were identified to have the following annual available flow during an average year (in acre feet): Antelope Creek (2,837), Cheyenne River above Gage 06365900 (3,696), Cheyenne above Sheep Creek (6,341), Cheyenne River above Black Thunder Creek (7,074), Black Thunder Creek (5,120), Cheyenne River above Lodgepole Creek (12,193), and Cheyenne River above Snyder Creek (12,674).

Stream Geomorphology **-** A Rosgen Level I classification was completed across the main tributaries of Thunder Basin. Figure ES-F2 illustrates the classifications and the results are summarized as follows: The majority of the stream channels are classified as B (moderately entrenched, moderate gradient, riffle dominated channel, with infrequently spaced pools, very stable plan and profile with stable banks) and C channels (low gradient, meandering, point-bar, riffle/pool, alluvial channels with broad, well defined floodplains). The Type G channels, or gullies, are typical in the upper reaches where the slope breaks and the head cut features formed along the slopes. Channel reaches of the Cheyenne River and tributaries are still adjusting their dimensions but are moving toward a more stable form.

Land Uses and Management Activities

Land Ownership - The majority of land in Thunder Basin is privately owned with the second largest landowner being the Federal Government. Land ownership will play an important role in project implementation in that permitting and financing options depends heavily on land ownership and intended beneficial use.

Range Conditions – Shrub abundance varies response to both substrates and range condition. Stress in the form of drought, or long-lasting grazing, can encourage the establishment of shrubs, as grass competition is lessened. Based on state and transition model information present in the NRCS Ecological Site Descriptions, most ecological sites of the Thunder Basin area can be expected to come to experience greater shrub cover as the effects of stress compound. It is important to note that grazing effects are likely not responsible for the presence of sagebrush in all cases. Extended drought is also an effective stressor. Some evidence also supports the view that sagebrush (and even abundant sagebrush) is a natural plant community component and not a vestige of stress, with abundance proportional to precipitation and snow cover (WGFD 2009).

Oil and Gas Production – The petroleum industry has been exploring and producing oil and gas in Wyoming for over 124 years and since that time, oil and gas production has become an important economic commodity in Thunder Basin. In the last 10 years there has been a decrease in the number of new oil wells and a substantial increase in the number of CBM wells, especially in southeastern Campbell County. This trend is expected to continue into the foreseeable future with increased demands on domestic sources of oil and gas.

Mining and Mineral Resources – Thunder Basin is the single largest source of coal mined in the United States and contains one of the largest deposits of coal in the world. The mines in Thunder Basin produce low-sulphur, sub-bituminous coal suitable for power station fuel without any preparation except crushing. Coal production is expected to continue into the foreseeable future with the potential for expansion as the energy demands increase across the nation. Other mineral deposits within Thunder Basin include uranium, which has a similar outlook for production in response to energy demand.

Watershed Inventory

Irrigation Inventory – Irrigation systems to irrigate grass/hay fields are documented on less than 1 percent of Thunder Basin. The systems are privately owned small spreader dike systems that irrigate areas ranging in size from less than 20 acres to several hundred acres. Most of the systems visited were not functional due to drought conditions and/or are in need of repair. Significant improvement in the systems could be achieved through sediment removal and/or replacement or repair of diversion structures.

Groundwater – Groundwater is used for livestock/wildlife watering but not for irrigation purposes. The reason for this has to do with the depth and yield of the aquifers in Thunder Basin. Groundwater is a viable resource for livestock/wildlife watering and should be expanded in areas where watering opportunities are scarce.

Water Storage Inventory – There are no natural lakes of significant size in the Thunder Basin watershed, however, there are 67 dams within the Thunder Basin study area. The combined storage behind the identified dams is 19,741 acre-feet. Available water for water storage projects was described above. Based on available stream gage and modeling information, during years of average precipitation, there is adequate available water for storage

opportunities. The study area contains approximately 194 small impoundments and stock watering ponds. There are 119 breached dam locations with a median pond size of 0.3 acres and a median estimated volume of 1.5 acre-feet. The total estimated volume that could be achieved by rehabilitation of the dams was 1,096 acre-feet. Rehabilitation of the breached dams within Thunder Basin could provide viable livestock/wildlife watering opportunities.

Water Quality – Based on a recent study of surface water quality, total dissolved iron levels were high and sometimes exceeded WDEQ criteria levels in the streams. The water quality criteria most often exceeded in samples collected throughout Thunder Basin were sulfate, specific conductance, and manganese. Exceeding the criteria does not necessarily indicate that water is unsuitable for livestock watering or agriculture. It does suggest that livestock and less tolerant plants might not be as productive as they would be with lower levels of the constituent.

Economic Analysis and Project Financing

- An economic analysis on the watershed rehabilitation plans proposed in this report was completed that included an indirect benefits analysis, ability to pay analysis and an evaluation of WWDC financing guidelines. Based on this analysis the livestock watering (upland well development) improvement projects appear to be the most economically beneficial to the association based purely upon a rate of return on their investment dollar.
- Project financing sources include federal, state, local and non-profit agencies. The primary sources of funding for the improvements presented in this report include the WWDC, NRCS and BLM. Numerous other opportunities are presented and should be pursued should the projects move to the next phase of implementation.

ES-2.2 Recommendations

Irrigation Systems

- Rehabilitation plans are proposed for each of the ditches inventoried as requested by ranchers/landowners in Thunder Basin (see Table ES-T1). The rehabilitation plans focus on rehabilitation/replacement of existing structures, enhanced delivery of water, reduction in annual operation and maintenance costs, improvement in ditch management and efficiency, and economic practicality and physical feasibility. Additional improvements could be made across Thunder Basin using the plans and cost estimates provided in this report as a guide for conceptual design, cost, and financing opportunities.
- The recommendations include regrading ditches, head gate replacements, and construction of spreader dikes. The cost estimates for the projects range from $14,700 to construct spreader dikes to $55,285 to build a 1,000 foot dike and regrade nearly one mile of ditch.
- The recommended improvements include thirteen different projects at four ranches. The individual projects can be implemented individually or as a complete package based on the preferences and financial ability of the owner. The most likely sources of funding for these projects is the WWDC Small Water Project Program and programs through the NRCS.

Surface Water Storage

- An evaluation of water available for storage projects was completed based on the existing datasets accessible for such an analysis. It is recommended that if any of the proposed Account III storage projects is undertaken that StateMod or similar model be developed so that water rights can be appropriately exercised and potential water availability can be more accurately estimated.
- Due to the lack of streamflow and watershed yield data, temporary stream gages should be installed at sites for which storage projects are desired.
- Four WWDC Account III multipurpose storage sites were identified in Thunder Basin. Key information about the sites is included in Table ES-T2 and their locations are illustrated on Figure ES-F3). Based on the financial evaluations and local landowner input, it is unlikely that any requests for Level II studies of these sites will move forward. They remain, however, sites that could be further evaluated in the future.
- Property owner storage evaluation requests were completed and four projects are recommended for further study and/or implementation. The projects include a storage reservoir on Sand Creek near the Haefele Ranch, construction of a dam on the Cheyenne River downstream of an existing run-of-the river dam that diverts water to the Harshbarger property, rehabilitation of Sherwin Dam, also on the Harshbarger property, and construction of a dam on Red Rock Draw near the Moore property.
- Livestock/wildlife watering opportunities were evaluated based on the assumption that cattle will graze up to a mile from a water source. Using this criterion, an analysis of the watershed was conducted to identify locations where additional water storage for livestock watering could be beneficial. Figure ES-F4 illustrates the results of this analysis.
- Supplemental storage at existing breached dam locations is a viable option to address the areas underserved with the existing network of stock wells and functional stock ponds (see Figure ES-F5). Six breached dams were identified outside of the cattle grazing ranges around existing water sources. The cost associated with rehabilitation of the breached dams ranged in cost from $20,000 to $44,000. The most likely source of funding for breached dam rehabilitation is the WWDC Small Water Project Program, the Wyoming Wildlife and Natural Resource Trust, or the Bureau of Land Management Range Improvement Planning and Development Program.
- For expansion of existing reservoirs, each of the 67 dams identified in the NID and shown in Figure ES-F5 was evaluated to determine whether each dam has enough watershed area to yield a minimum of 1,000 acre-feet of available water based on the averages described in the preceding paragraph. Of the 67 dams, only one dam emerged as a potential site, "Peterson No. 1" located on Black Thunder Creek downstream of Dull Center Road and upstream of the confluence with the Cheyenne River. It is estimated that the cost to expand the dam to capture and store a minimum of 1,000 acre-feet would be approximately $6 to $7 million based on the average cost per acre-foot of stored water developed for new dams presented in this report.

Groundwater Development

- One of the best options to enhance rangeland and riparian habitat is to ensure that there are adequate watering opportunities in the upland areas of the watershed. Currently drainage ways are often the location of the water that is available and therefore livestock pressure in these portions of the landscape is disproportionately great. With dispersal of livestock watering sources to uplands, not only are riparian areas relieved of grazing and trampling pressure, but little used forage on remote uplands may be accessed by foraging animals. For these reasons five upland water development projects in underserved areas are recommended (Table ES-T3). All five upland water development projects are recommended for funding through the WWDC Small Water Project Program. These projects include the combinations of the following elements: installation of shallow to moderately deep groundwater wells, solar powered pumps, stock tanks, piping and fencing to maximize water distribution for livestock and wildlife. The projects range in cost from $15,900 to $89,800.
- Additional upland water development improvements could be made across Thunder Basin using the plans and cost estimates provided in this report as a guide for conceptual design, cost, and financing opportunities.
- Development of deep aquifer irrigation wells is not deemed feasible for this area unless significant advances in technology for installation and long-term pumping are realized.

Other Management Practices

- Control of noxious weeds including Russian olive, salt cedar and Canada thistle, to name a few, should continue to be implemented to promote overall health of the rangeland. Efforts should be concentrated in areas of large infestations in both rangeland and riparian areas.
- Continued implementation of the grazing management plans developed for the Thunder Basin is recommended. These plans provide methods for pasture rotation and riparian habitat protection that will continue to add to the value and health of the watershed.
- Based on the geomorphologic evaluation completed across Thunder Basin, it is recommended that channel restoration and stabilization efforts should be coordinated as the proposed projects are implemented. For example, at the Harshbargers' ranch a series of cross vane type structures could be constructed to provide an increase in head elevation for the diversion point and at the Stroh ranch, as part of the headgate repair/replacement an in-channel diversion structure will be needed. Additionally, the large storage structures will require additional evaluations to ensure stream stability after project implementation. These more detailed geomorphologic evaluations (i.e., Level II Rosgen Classifications) can be implemented as part of the Level II feasibility studies that will be completed during the next phase of project implementation.

Tables

Table ES-T1 Proposed Irrigation Improvements

Rehabilitation Item Number	Ranch Name	Description	Units	Quantity	Unit Cost	Total Cost
Cheyenne Watershed (Black Thunder Creek) Improvements						
1	Stroh	Repair/Replace Head gate and install diversion structure	LS	1	-	$15,000
2	Stroh	Re-grade ditch 1	FT	2481	$5/FT	$12,405
3	Stroh	Repair/Replace Siphon	LS	1	-	$10,000
4	Stroh	Re-grade ditch 2	FT	3174	$5/FT	$15,870
5	Stroh	Re-grade ditch 3	FT	1263	$5/FT	$6,315
Cheyenne Watershed (Cheyenne River) Improvements						
6	Harshbarger	Re-grade ditch	FT	1600	$5/FT	$8,000
7	Harshbarger	Re-grade ditch	FT	5165	$5/FT	$25,825
8	Harshbarger	Repair/Replace Headgate	LS	1	-	$5,000
Antelope Creek Watershed Improvements						
9	Turner	Construct Spreader dikes	FT	420	$35/FT	$14,700
Dry Fork Cheyenne Watershed Improvements						
10	Pellatz	Install new headgate	EA	1	5000	$5,000
11	Pellatz	Re-grade ditch 1	FT	7778	$5/FT	$38,890
12	Pellatz	Re-grade ditch 2	FT	4057	$5/FT	$20,285
13	Pellatz	Build new dike	FT	1000	$35/FT	$35,000

ES-T2. Alternative Surface Water Storage Sites

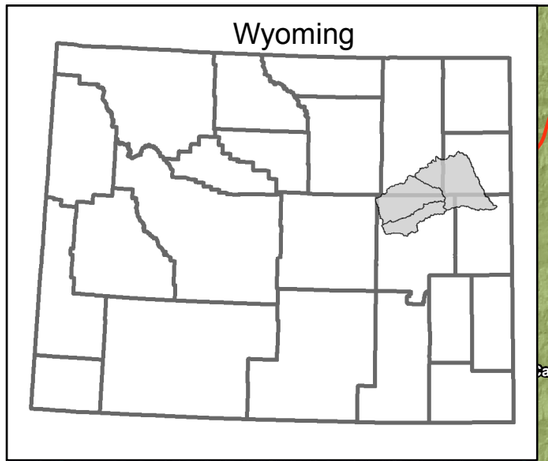
Potential Dam Sites	Antelope Creek	Cheyenne River 1	Cheyenne River 2	Black Thunder Creek
Local Information				
USGS 7.5-minute Topographic Quadrangle	Betty Reservoir	Poddy Creek	The Nose West and East	Darlington Draw East
County	Converse	Weston	Weston	Weston
Onstream / Offstream	Onstream	Onstream	Onstream	Onstream
Basin Characteristics and Hydrology				
Drainage Area (mi^2)	777	1,713	2,335	506
Estimated PMF Flood Characteristics				
Estimated Peak Discharge (cfs)	158,605	244,399	301,417	133,753
Estimated Runoff Volume (ac-ft)	394,373	924,815	1,277,344	240,715
Annual Peak Flow Characteristics				
Region	Eastern Basins/Plains	Eastern Basins/Plains	Eastern Basins/Plains	Central Basins/Northern Plains
Average Annual Precipitation (in)	14.0	14.0	14.0	14.0
Average Annual Available Water (ac-ft)	2,134	6,904	12,071	4,551
Reservoir Characteristics and Operation				
Normal High Water				
Capacity (ac-ft)	3,509	5,840	8,575	2,879
Surface Area (ac)	311	527	764	320
Water Surface Elevation	4615.40	4142.00	3999.50	4191.20
Average Water Depth (ft)	11	11	11	9
Site Geology				
Geology				
Karst				
Klinker				
Seepage				
Structure				
Liquefaction Potential				
Disperse/Soluble Soils				
Foundation Strength				
Reservoir Rim Conditions				
Landslide Deposits				
Bedrock Geology Units	Tfl	Qa, Tft	Kl, Qa	Tft
Surficial Geology Units	ai, ri	ai, ti, tdi	ai, sci, ti, ri	ai
Borrow				
Relative apparent availability				
Relative apparent quality				
Site Environmental Conditions				
Environmental Issues				
NWI Wetlands (ac)	0.0	19.5	13.0	1.9
Stream Classification (Rosgen)				
WYDEQ Stream Classification	3B	2ABWW	2ABWW	3B
Sage Grouse Leks				
Big Game Habitat - Crucial				
Big Game Parturition (Birthing Areas)				
Raptor Nesting Area				
Mineral Resources				
Coal Potential				
Uranium				
Sulfur				
Bentonite				
Other Metals				
Infrastructure and Ownership				
Infrastructure/Utilities Conflicts				
Residences/Facilities	2	0	0	4
Highways (mi)	0.1	0	0	0
Railroads (mi)	0	0	0	0
Pipelines (mi)	0	0	0	0
Transmission Lines1 (mi)				
Transmission Lines2 (mi)				
Distribution Lines1 (mi)				
Irrigated Lands (ac)	0	0	0	0
Energy Resources				
Oil Field		X	X	
Gas Field				
Land Ownership				
Private	X	X	X	X
State		X		
Federal				
Dam Characteristics and Hydraulic Structures				
Dam				
Freeboard/Head Spillway (ft)	12.34	13.76	13.83	12.93
Crest Elevation (ft)	4627.74	4155.76	4013.33	4204.13
Total Crest Length (ft)	1,300	3,600	3,270	2,320
Crest Width (ft)	14	14	14	14
Maximum Dam Height (ft)	43	39	46	40
Foundation Excavation Volume (1000 cy)	96	219	153	132
Total Earthwork Fill Volume (1000 cy)	482	1,094	766	662
Storage Efficiency (ac-ft/1000 cy)	7.3	5.3	11.2	4.3
Height Efficiency (ft/1000 ac-ft)	12.1	6.8	5.4	13.9
Outlet Works				
Proposed Type	Conduit	Conduit	Conduit	Conduit
Outlet Elevation	4585.23	4116.32	3967.29	4164.16
Principle Spillway				
Proposed Type	Concrete Chute	Concrete Chute	Concrete Chute	Concrete Chute
Crest Elevation (ft)	4615.40	4142.00	3999.50	4191.20
Design Capacity (cfs)	51,750	85,745	98,885	15,710
Approximate Width (ft)	385	542	620	109
Approximate Length (ft)	95	81	102	86
Emergency Spillway				
Crest Elevation (ft)	4622	4149	4006.5	4197.25
Design Capacity (cfs)	27,553	36,454	51,823	51,166
Approximate Width (ft)	700	800	1,200	1,200
Approximate Length (ft)	1,226	1,089	1,307	1,103
Cut Volume (1000 cy)	91	109	198	169
Supply and Delivery Facilities				
Supply Diversions				
Length (mi)				
Terrain				
Delivery Canals				
Length (mi)				
Terrain				
Other				
Access				
Cultural Resources				
Costing				
Total Project Cost	$1,367,000	$737,000	$12,915,000	$60,000
Total Project Cost per cy of Fill	$2.83	$0.67	$16.87	$0.09
Total Project Cost per ac-ft of Storage	$390	$126	$1,506	$21

Excellent or more than adequate
Favorable or adequate
Marginal or unfavorable value
Probable fatal flaw or very unfavorable value

Table ES-T3 Upland Water Well Development Projects

Project Number	Ranch Name	Well Install	Solar System	Pipeline Length (feet)	Fencing (feet)	Site Prep	Stock Tanks	Estimated Cost
Antelope Creek Watershed Improvements								
1	Bell	2	1	0	0	2	2	$37,200
2	Haefele	1	0	0	5280	1	1	$33,940
3	Moore	3	3	15000	15000	3	6	$89,800
Upper Cheyenne Watershed Improvements								
4	Lynch	1	1	0	0	1	1	$15,600
5	Stroh	1	1	5000	10000	1	2	$57,900

Figures



LEGEND

- Watersheds
- Counties
- Cites
- Generalized Streams
- Generalized Lakes
- Major Roads

Wright
Weston
Osage
Upper Cheyenne
Antelope
Bill
Natrona
Converse
Niobrara
Lance Creek
Campbell

Black Thunder Creek
Little Thunder Creek
Lodgepole Creek
Hay Creek
Wildcat Creek
Porcupine Creek
Bates Creek
Antelope Creek
Bear Creek
Sand Creek
Snyder Creek
Cheyenne River
Lance Creek
North Fork Bear Creek
Dry Fork Cheyenne River
Dry Fork Cheyenne

WYOMING 116
WYOMING 450
WYOMING 387
WYOMING 59

T46N R69W, T46N R68W, T46N R67W, T46N R66W, T46N R65W
T45N R70W, T45N R69W, T45N R68W, T45N R67W, T45N R66W, T45N R65W
T44N R71W, T44N R70W, T44N R69W, T44N R68W, T44N R67W, T44N R66W, T44N R65W, T44N R72W
T43N R73W, T43N R72W, T43N R71W, T43N R70W, T43N R69W, T43N R68W, T43N R67W, T43N R66W, T43N R65W, T43N R64W
T42N R75W, T42N R74W, T42N R73W, T42N R72W, T42N R71W, T42N R70W, T42N R69W, T42N R68W, T42N R67W, T42N R66W, T42N R65W, T42N R64W
T41N R76W, T41N R75W, T41N R74W, T41N R73W, T41N R72W, T41N R71W, T41N R70W, T41N R69W, T41N R68W, T41N R67W, T41N R66W, T41N R65W, T41N R64W, T41N R63W
T40N R77W, T40N R76W, T40N R75W, T40N R74W, T40N R73W, T40N R72W, T40N R71W, T40N R70W, T40N R69W, T40N R68W, T40N R67W, T40N R66W, T40N R65W, T40N R64W, T40N R63W, T40N R62W
T39N R77W, T39N R76W, T39N R75W, T39N R74W, T39N R73W, T39N R72W, T39N R71W, T39N R70W, T39N R69W, T39N R68W, T39N R67W, T39N R66W, T39N R65W, T39N R64W, T39N R63W, T39N R62W
T38N R77W, T38N R76W, T38N R75W, T38N R74W, T38N R73W, T38N R72W, T38N R71W, T38N R70W, T38N R69W, T38N R68W
T37N R76W, T37N R75W, T37N R74W, T37N R73W, T37N R72W, T37N R71W
T36N R76W, T36N R75W, T36N R74W, T36N R73W, T36N R72W

PROJECT: 008-1217 DRAWN BY: RD DATE: 11/25/2009	Source: Streams, 2006, ESRI; Watershed, 2002, WYGISC; DEM, 2008, USGS Roads, 1997, TIGER; Counties, 2007, SDVC; Cities, 2006, ESRI;	3.5 0 3.5 7 10.5 Miles 1:443,520 N	**STUDY AREA LOCATION** **Thunder Basin Watershed Study** **Northeast Wyoming**	OLSSON ASSOCIATES	Figure ES-F1

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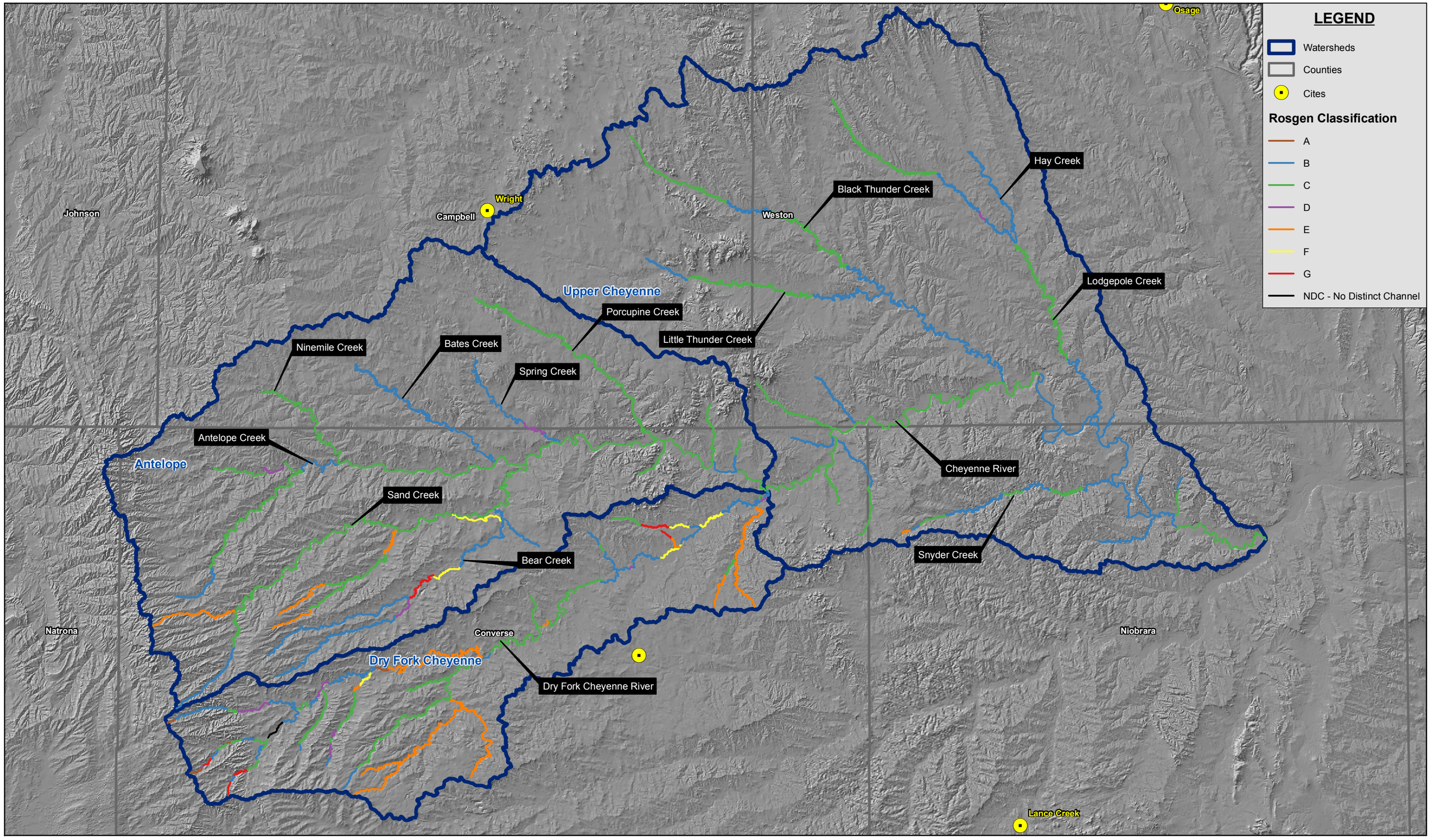

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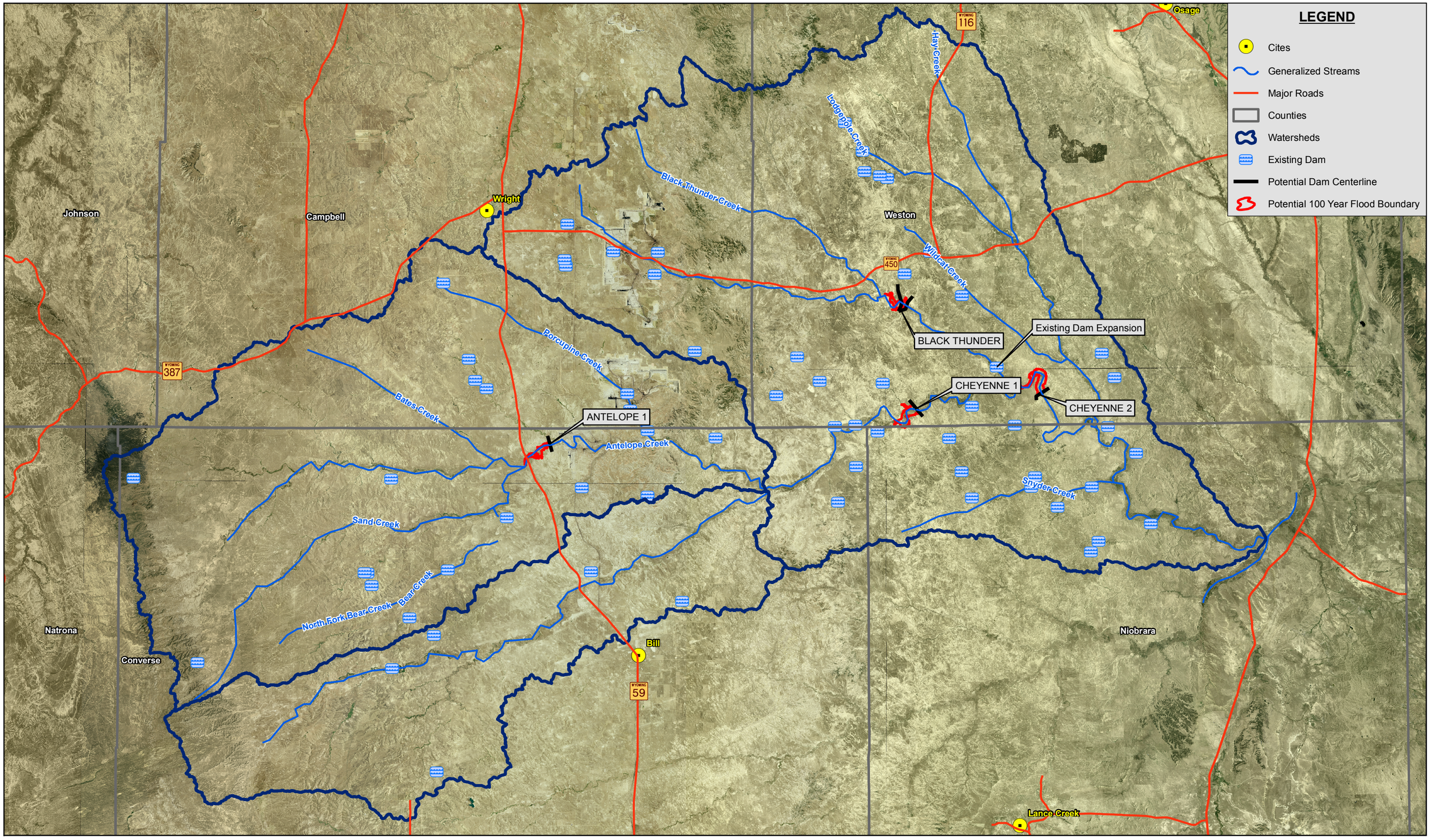
PROJECT: 008-1217 DRAWN BY: RD DATE: 11/25/2009	Source: Streams, 2006, ESRI; Watershed, 2002, WYGISC; DEM, 2008, USGS Roads, 1997, TIGER; Counties, 2007, SDVC; Cities, 2006, ESRI; Watershed Boundaries, 2005, USGS	3.5 0 3.5 7 10.5 Miles 1:443,520 N	**MAJOR STREAMS WITH ROSGEN CLASSIFICATION** **Thunder Basin Watershed Study** **Northeast Wyoming**	OLSSON ASSOCIATES Figure ES-F2



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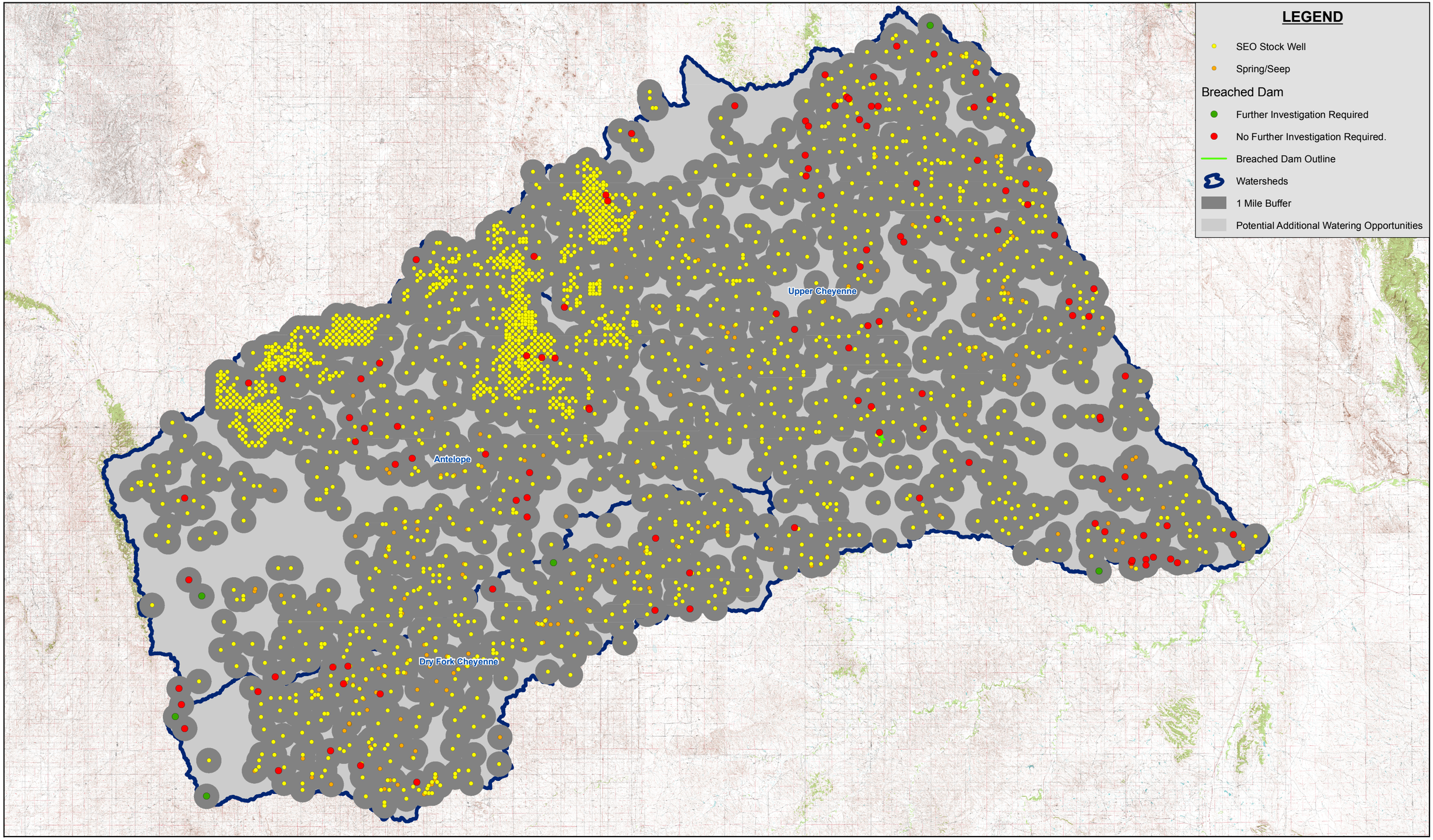
PROJECT: 008-1217 DRAWN BY: RD DATE: 11/25/2009	Source: Streams, 2006, ESRI; Watershed, 2002, WYGISC; DEM, 2008, USGS Roads, 1997, TIGER; Counties, 2007, SDVC; Cities, 2006, ESRI;	3.5 0 3.5 7 10.5 Miles 1:443,520 N	**POTENTIAL SURFACE WATER STORAGE SITES** **Thunder Basin Watershed Study** **Northeast Wyoming**	OLSSON ASSOCIATES	Figure ES-F3



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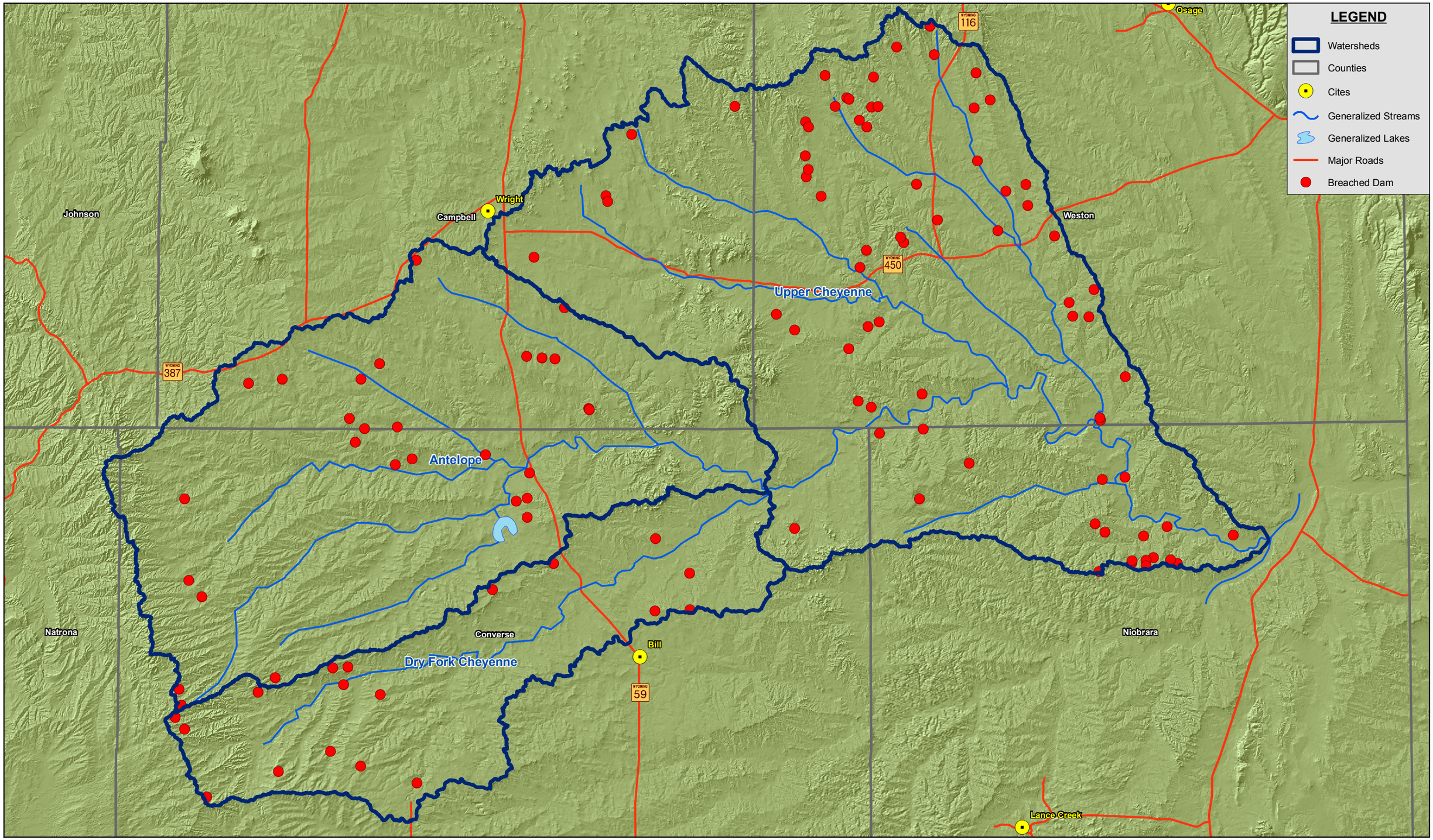
PROJECT: 008-1217 DRAWN BY: RD DATE: 11/25/2009	Source: Streams, 2006, ESRI; Watershed, 2002, WYGISC; DEM, 2008, USGS Roads, 1997, TIGER; Counties, 2007, SDVC; Cities, 2006, ESRI;	3.5 0 3.5 7 10.5 Miles 1:443,520 N	**EXISTING WILDLIFE/LIVESTOCK WATERING OPPORTUNITIES** **Thunder Basin Watershed Study** **Northeast Wyoming**	OLSSON ASSOCIATES	Figure ES-F4



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PROJECT: 008-1217 DRAWN BY: RD DATE: 11/25/2009	Source: Streams, 2006, ESRI; Watershed, 2002, WYGISC; DEM, 2008, USGS Roads, 1997, TIGER; Counties, 2007, SDVC; Cities, 2006, ESRI; Watershed Boundaries, 2005, USGS	3.5 0 3.5 7 10.5 Miles 1:443,520 N	**BREACHED DAM LOCATION MAP** **Thunder Basin Watershed Study** **Northeast Wyoming**	OLSSON ASSOCIATES	Figure ES-F5