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Cheyenne Belvoir Ranch
Groundwater Level II

Executive Summary

Prepared for:

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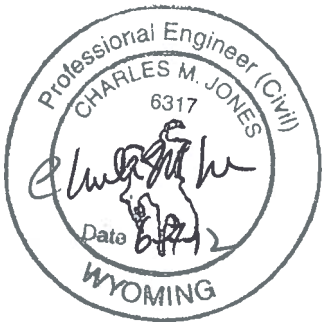

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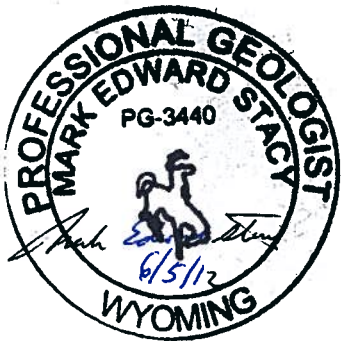

June 2012

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1.0 Introduction

In 2009 with authorization from the 62nd Wyoming State Legislature, the Wyoming Water Development Commission (WWDC) retained Lidstone and Associates, Inc. (LA), to complete a Level II well siting and test well drilling project on the Belvoir Ranch (Ranch) for the Cheyenne Board of Public Utilities (BOPU), the project sponsor. LA teamed with AMEC Earth and Environmental and Zonge Geosciences (Zonge) to complete the exploration and development of the Casper Aquifer beneath the western portion of the Ranch.

During the Paleozoic Ground Water Exploration Grant Project in 2005-2006, the completion of three test wells, Lone Tree No. 1, Duck Creek No. 1, and Kennedy No. 2, demonstrated that the Casper Aquifer at the Ranch can yield significant volumes of groundwater to wells. Completing high capacity wells, however, is complicated by the complexity of the hydrogeology of the Casper Aquifer. Lone Tree No. 1 yielded up to 782 gallons per minute (gpm) of high quality groundwater during drilling and subsequent test pumping. In contrast, Duck Creek No. 1 yielded only 24 gpm during development and was not test pumped.

The success of the Lone Tree No. 1 well, contrasted with the low yield of the Duck Creek No. 1 well, confirmed that the development of high capacity Casper Aquifer wells depends in part upon drilling through highly permeable, water bearing features on geologic structures. Locating the right spot on the structure is complicated by the fact that the Casper Aquifer is covered by Tertiary sedimentary rock formations.

1.1 History and Project Background

The City of Cheyenne purchased the Ranch in June of 2003 with the intent to utilize the property for a variety of purposes, including the development of its water resources from both the High Plains and Casper Aquifers. Since 2004, the WWDC with the BOPU as the sponsor has completed three studies to evaluate the water resources of these aquifers.

In addition to the water available from the High Plains Aquifer, groundwater from the Casper Aquifer could help meet future water demand for the BOPU. This development could potentially be accomplished without adversely impacting downstream water users. Groundwater from the Casper Aquifer is far removed from adjacent groundwater rights connected to the High Plains Aquifer, as well as surface water rights on the eastern end of the Ranch. Development of the Casper Aquifer demonstrates the city's good faith effort to find additional supplies beyond the Stage I and II surface water diversions from sources located on the western slope. Because it is hydrologically isolated from the former Atlas Site "D" Missile facility, groundwater from the Casper Aquifer is free of trichloroethene.

1.2 Authorization and Purpose

This Level II feasibility study was undertaken to further evaluate the water resource potential of the Casper Aquifer beneath the western third of the Ranch. The BOPU needs to know how much additional groundwater may be obtained from this aquifer south of the Lone Tree No. 1 well to make cost effective planning decisions.

The purposes of this project were to:

- ✓ Evaluate the groundwater production capabilities of the Casper Aquifer on the western side of the Ranch.

- ✓ Identify potential drilling sites to develop the groundwater resources of this aquifer using available well completion methods.
- ✓ Drill test wells to evaluate Casper Aquifer yield and water quality, and to produce water for the BOPU.
- ✓ Develop and/or refine potential transmission line alternatives to deliver water from the Casper Aquifer to the BOPU's existing infrastructure.
- ✓ Prepare conceptual designs, cost estimates, financing and economic analysis of sufficient detail to move this project towards a Level III Construction phase, as warranted.

Within the available funding, the project team conducted a geologic and geophysical investigation to identify potential well sites, and completed four 8 5/8-inch diameter test wells in the Casper Aquifer. These wells included Duck Creek 3-1, Lone Tree Fault 1-2, Goose Creek 2-2C, and Lone Tree Fault 1-5. While yields of these wells ranged from 30 to 200 gpm, it was the 200 gpm production of Duck Creek 3-1 near Duck Creek No. 1 that indicated the potential yield of the Duck Creek Anticline area was higher than previously estimated.

Based on the data from the six completed Casper Aquifer test wells, LA has reevaluated the geologic and hydrogeologic character of the aquifer on the Ranch. Alternatives for potential Casper Aquifer well fields have been identified, and conceptual designs are presented for wells, appurtenances, and transmission lines. Cost estimates in 2012 dollars are provided for the alternatives along with current BOPU financial planning, and estimates for future financing of the proposed alternatives.

2.0 Potential Casper Aquifer Well Fields

Based on the geologic, hydrogeologic, and geophysical interpretation of the data obtained, two well fields and a number of locations for exploratory wells have been identified. The key to successful development of the well fields is locating wells where permeability enhancement of the upper Casper Formation will lend itself to increased well yields. In some instances, especially at the Duck Creek well field, drilling depth predictions based on geologic interpretations vary from predictions based on revised geophysical interpretations. It should be noted that drilling depths and costs associated with the proposed wells may vary depending on actual subsurface conditions encountered.

The proposed Lone Tree Creek Well Field consists of seven production wells, LTC 1 – LTC 7, that are located along Lone Tree Creek in the northwestern corner of the Ranch. This field may be capable of yielding approximately 2,000 gpm with only four of these wells pumping at any given time. Assuming this production occurred over a 120 day summertime operational period, the well field would deliver approximately 1,060 acre feet annually. This field owes its productivity to the recharge of Lone Tree Creek, and permeability enhancement associated with the intense southeastward folding along Granite Springs Anticline, cavity formation, and eastward faulting. Individual wells in this field may be capable of yielding 400 to 500 gpm, and well depths may range from 1,280 to 2,760 feet.

The proposed Duck Creek Well Field consists of six production wells, DC 1 – DC 6, that are located along Duck Creek in the west central portion of the study area. Based on the hydrogeologic parameters derived from the Duck Creek 3-1 aquifer tests, this field may be capable of yielding 600 gpm from three wells that would be pumping simultaneously. Assuming this production occurred over a 120 day summertime operational period, the well field would

deliver approximately 318 acre feet annually. The production of this field is due to recharge from Duck and Goose Creeks, and permeability enhancement of the Casper Formation associated with structural deformation along the Duck Creek Anticline. Individual wells in this field may be capable of yielding 200 gpm, and the permeability and yield potential may increase with wells drilled along the anticlinal axis south of Duck Creek 3-1. Differences in the geologic and geophysical interpretations of the Casper Formation top are significant in this area. While the difference is only 100 feet at DC 1, that difference is estimated to be approximately 2,200 feet at DC 4. While LA anticipates drilling depths range from 1,925 to 3,870 feet, those depths could be shallower and drilling costs could be less if the geophysical interpretation proves to be more representative of actual conditions.

The geologic and geophysical interpretations for the top of the Casper Formation differ for several reasons. The geologic interpretation was developed from outcrop bedding attitudes, observed geologic structure, test well drilling data, and aquifer test results. In contrast, the geophysical interpretation is based on seismic reflection data, CSAMT resistivity data, test well drilling data, and formation velocities. Differences in the interpretation of depths to the Casper Formation top arise from the uncertainties associated with the different approaches. These uncertainties include, but are not limited to, changing formation velocities, variable formation thickness and lithology, concealed or unrecognized geologic structure, and changing formation dip away from outcrop. Any or all of these could account for the differences in potential drilling depths at any given location.

With two potential well fields and additional exploration areas identified, the Casper Aquifer represents a significant groundwater development opportunity for the BOPU on the west end of the Belvoir Ranch. Despite the significant information obtained from this study, questions still remain regarding details of the complex geologic structure and its impact upon Casper Aquifer hydrogeology. These questions include the following:

1. How much water is recharged to the Casper Aquifer annually from Lone Tree, Goose, and Duck Creeks via their respective stream sinks?
2. Where are the permeable conduits in the Casper Aquifer below the groundwater divide near the former Atlas missile site, and how much additional water might they yield?
3. Why is the Casper Formation along the Lone Tree Creek Fault line so shallow based on test well drilling, and how does any geologic structure present in this area affect recharge heading south toward Duck Creek Anticline?
4. What structure underlies the Duck Creek Anticline area that creates such dramatic dip changes, and what impact will that have on future groundwater development in the vicinity of this well field?
5. What permeability features exist across Duck Creek Anticline that result in lower Casper Aquifer water levels across this area, and will they yield water more efficiently than Duck Creek 3-1?
6. What type of structure, if any, lies between Duck Creek Anticline and Spottlewood Anticline and what is its hydrogeologic impact?
7. What yield potential does Spottlewood Anticline have given its apparent low recharge, but complex geologic structure?
8. What other geologic structures are present that affect the Casper Formation subsurface configuration and potential aquifer yield?

To address these questions, the project team recommends a phased approach that combines further geophysical exploration with test well drilling prior to completing the proposed wells as municipal water supply wells. Production size test wells would be initially completed with open boreholes through the upper part of the Casper Formation. If subsequent aquifer testing results in adequate yield, then the wells would be fully completed in the Casper Aquifer with screen and gravel pack.

3.0 Well Field and Transmission Line Development

Based upon the positive results of the exploration effort to date, but also deep drilling depths, outstanding questions, and costs to complete the well fields, the development of this resource in a phased approach is warranted. To detail the costs of this proposed well field development, two phases are presented that are each subdivided into a geophysical exploration and test well drilling phase, and a well completion and transmission line phase.

3.1 Phase 1 - Lone Tree Creek Well Field

Exploration and development of the Lone Tree Creek Well Field is proposed as the first phase development of the Casper Aquifer. Subphase (1A) involves additional surface geophysical exploration, and completing test production wells at the Lone Tree Creek Well Field. This phase also includes further exploration of the potential expansion areas identified northeast of Lone Tree Creek Fault and beneath the former missile site. The geophysical data acquisition would consist of 2D seismic reflection and CSAMT resistivity. Subphase (1B) involves completing the wells with screen and gravel pack, and constructing the associated infrastructure to deliver this water to the BOPU water system.

Additional surface geophysical data acquisition and interpretation is recommended in Subphase 1A to integrate previous geophysical and test well drilling data in advance of drilling production sized test wells. The rationale for completing the additional lines in the Lone Tree Creek area is as follows:

- ✓ Tie into the geologic and geophysical information obtained during the 2005 and 2009 Zonge geophysical surveys and subsequent test well drilling;
- ✓ Define geologic structure and permeable pathways along Granite Springs Anticline;
- ✓ Identify permeability pathways for recharge from Lone Tree Creek to Casper Aquifer northeast of Lone Tree Creek Fault; and
- ✓ Refine drilling locations and depths for production sized test wells to be drilled for Lone Tree Creek Well Field and in potential exploration areas beneath and south of the former Atlas missile site.

Following the geophysical acquisition and reinterpretation, the locations of the test production well sites would be refined. The test wells would be completed with 10 3/4-inch diameter casing and an open borehole in the Casper Aquifer without screen and gravel pack. Initially completing the wells in this fashion allows for further exploration of the aquifer, and provides a suitable well diameter for screen installation and appropriate pumping equipment placement after the field has been proven successful. If suitable production is obtained, the number of wells in the field could be adjusted along with the associated infrastructure and costs. The estimated cost to complete Subphase 1A is as follows:

Table 1 Phase 1A – Lone Treek Creek Well Field Exploration Costs

Item	Unit	Estimated Quantity	Unit Price	Cost
Surface Geophysics[1]				
Data Compilation	Lump Sum	1	$25,000	$25,000
Mob/Demob	Lump Sum	1	$25,000	$25,000
Seismic Reflection	Mile	8.6	$11,500	$98,900
CSAMT Survey	Mile	8.6	$6,000	$51,600
Reporting	Lump Sum	1	$10,000	$10,000
Wells[2]				
LTC 1	Feet	1280	$275	$352,000
LTC 2 (5-2)	Feet	1485	$275	$408,375
LTC 3 (5-4)	Feet	2760	$275	$759,000
LTC 4	Feet	1320	$275	$363,000
LTC 5	Feet	2085	$275	$573,375
LTC 6	Feet	1600	$275	$440,000
LTC 7	Feet	2255	$275	$620,125
PE 1 (1-4)	Feet	2435	$275	$669,625
PE 2 (1-6)	Feet	2525	$275	$694,375
Subtotal 1				$5,090,375
Engineering @ 10% of Subtotal 1				$509,038
Subtotal 2				$5,599,413
Contingency @ 15% of Subtotal 2				$839,912
Total Construction Costs				$6,439,324
Hydrogeology/Well Design				$10,000
Permitting				$9,000
Final Plans and Specifications				$20,000
Reporting				$25,000
			Total Costs	**$6,503,324**

Note: Costs are based on 2012 dollars

1 - Includes 2D seismic reflection and CSAMT resistivity surveying

2 - Cost does not include screen and gravel pack. Open hole completions.

Assuming the test production well completions are successful, Subphase (1B) is to complete the test wells at the Lone Tree Creek Well Field as production wells along with the associated infrastructure and transmission pipelines. This subphase would include a 24-inch diameter transmission main that would provide the necessary capacity for additional well fields as they are developed to the south. For this phase of construction, the transmission pipeline to the south would extend to the vicinity of PE 1. The estimated cost to complete Subphase (1B) is as follows:

Table 2 Phase 1B – Lone Tree Creek Well Field Completion Costs

Item	Unit	Estimated Quantity	Unit Price	Cost
Wells[1]				
LTC 1	Well	1	$180,000	$180,000
LTC 2 (5-2)	Well	1	$180,000	$180,000
LTC 3 (5-4)	Well	1	$180,000	$180,000
LTC 4	Well	1	$180,000	$180,000
LTC 5	Well	1	$180,000	$180,000
LTC 6	Well	1	$180,000	$180,000
LTC 7	Well	1	$180,000	$180,000
PE 1 (1-4)	Well	1	$180,000	$180,000
PE 2 (1-6)	Well	1	$180,000	$180,000
Pumping Equipment				
Mobilization	EA	9	$10,000	$90,000
Pump & Motor, 500 gpm Pump w/ column pipe and pitless unit	EA	7	$95,000	$665,000
Pump & Motor, 200 gpm Pump w/ column pipe and pitless unit	EA	2	$100,000	$200,000
Well Building & Piping	EA	9	$37,500	$337,500
Electrical Components, VFD and Telemetry & SCADA	EA	9	$110,000	$990,000
Miscellaneous Costs/Testing	EA	9	$10,000	$90,000
Well Field Transmission Pipeline System				
Transmission Main; 24 inch	LF	2000	$140	$280,000
Transmission Main; 16 inch	LF	12500	$100	$1,250,000
Well Field Pipe; 8 inch	LF	5000	$66	$330,000
Powerlines				
Primary Line	miles	2.1	$75,000	$157,500
Secondary Line	miles	1	$50,000	$50,000
Access Roads				
Main Access Route to the well field	LS	2.1	$210,000	$210,000
Primary Road	miles	2.25	$75,000	$168,750
Secondary Road	miles	1.25	$40,000	$50,000
Transmission Main Pipeline				
Transmission Main from Lone Tree Creek to Eastern Belvoir Ranch junction; 24 inch	LF	43000	$140	$6,020,000
			Subtotal 1	$12,508,750
			Engineering @ 10% of Subtotal 1	$1,250,875
			Subtotal 2	$13,759,625
			Contingency @ 15% of Subtotal 2	$2,063,945
			Total Construction Costs	$15,823,570
			Surveying	$60,000
			Geotechnical	$40,000
			Legal Costs	$15,000
			Easements	$20,000
			Permitting	$50,000
			Final Plans and Specifications	$250,000
			Total Costs	**$16,258,570**

Note: Costs are based on 2012 dollars

1 - Includes costs to complete production wells with screen and gravel pack.

3.2 Phase 2 – Duck Creek Well Field

The second phase involves exploration and development of the Duck Creek Well Field and associated exploration areas. Subphase (2A) involves additional surface geophysical exploration, and completing test production wells at the Duck Creek Well Field. It also includes further exploration of the potential expansion area along Goose Creek. The geophysical data acquisition would consist of 2D seismic reflection and CSAMT resistivity. Subphase (2B) involves completing the wells with screen and gravel pack, and constructing the associated infrastructure to tie these wells into the transmission line extending south from the Lone Tree Creek Well Field.

As with the Lone Tree Creek Well Field, additional surface geophysical data acquisition and interpretation is recommended in phase 2A to integrate previous geophysical and test well drilling data in advance of drilling production sized test wells. The rationale for completing the additional lines in the Duck Creek area is as follows:

- ✓ Tie into the geophysical and geologic information obtained from previous and future Lone Tree Creek exploration work;
- ✓ Define the structural configuration of the Casper Formation along the crest of Duck Creek Anticline;
- ✓ Determine the hydrogeologic impact, if any, of a possible strike slip fault between Duck Creek Anticline and Spottlewood Anticline; and
- ✓ Refine drilling locations and depths for production sized test wells to be drilled for the Duck Creek Well Field and potential expansion areas along Goose Creek.

Following the geophysical acquisition and reinterpretation, the locations of the test production well sites would be refined. As at the Lone Tree Creek Well Field, the test wells would be completed with 10 ¾-inch diameter casing and an open borehole in the Casper Aquifer without screen and gravel pack. If suitable production is obtained, the number of wells in the field could also be adjusted along with the associated infrastructure and costs. The estimated cost to complete Subphase (2A) is as follows:

Table 3 Phase 2A – Duck Creek Well Field Exploration Costs

Item	Unit	Estimated Quantity	Unit Price	Cost
Surface Geophysics[1]				
Data Compilation	Lump Sum	1	$25,000	$25,000
Mob/Demob	Lump Sum	1	$25,000	$25,000
Seismic Reflection	Mile	9.1	$11,500	$104,650
CSAMT Survey	Mile	9.1	$6,000	$54,600
Reporting	Lump Sum	1	$10,000	$10,000
Wells[2]				
DC 1	Feet	2410	$275	$662,750
DC 2 (3-2)	Feet	3200	$275	$880,000
DC 3 (3-3)	Feet	3685	$275	$1,013,375
DC 4 (3-4)	Feet	3870	$275	$1,064,250
DC 5	Feet	1570	$275	$431,750
DC 6	Feet	1925	$275	$529,375
PE 3 (2-1)	Feet	2030	$275	$558,250
PE 4 (2-3)	Feet	3550	$275	$976,250
PE 5 (2-5)	Feet	4135	$275	$1,137,125
			Subtotal 1	$7,472,375
			Engineering @ 10% of Subtotal 1	$747,238
			Subtotal 2	$8,219,613
			Contingency @ 15% of Subtotal 2	$1,232,942
			Total Construction Costs	$9,452,554
			Hydrogeology/Well Design	$10,000
			Permitting	$9,000
			Final Plans and Specifications	$20,000
			Reporting	$25,000
			Total Costs	**$9,516,554**

Note: Costs are based on 2012 dollars

1 - Includes 2D seismic reflection and CSAMT resistivity surveying

2 - Cost does not include screen and gravel pack. Open hole completions.

Assuming the test production well completions are successful, the final Subphase (2B) is to complete the test wells at the Duck Creek Well Field as production wells along with the associated infrastructure and transmission pipelines. This subphase would include extending transmission south from the Lone Tree Creek Well Field. For this phase of construction and for cost estimation purposes, the transmission pipeline to the south would extend to the vicinity of DC 4, or the southernmost production well. Future geophysical exploration may tie in the Spottlewood Anticline area, although it is currently considered a wildcat prospect based upon the information gathered to date. For that reason, it has not been included in the cost estimates for this project at this time. The estimated cost to complete Subphase (2B) is as follows:

Table 4 Phase 2B – Duck Creek Well Field Completion Costs

Item	Unit	Estimated Quantity	Unit Price	Cost
Wells[1]				
DC 1	Well	1	$180,000	$180,000
DC 2 (3-2)	Well	1	$180,000	$180,000
DC 3 (3-3)	Well	1	$180,000	$180,000
DC 4 (3-4)	Well	1	$180,000	$180,000
DC 5	Well	1	$180,000	$180,000
DC 6	Well	1	$180,000	$180,000
PE 3 (2-1)	Well	1	$180,000	$180,000
PE 4 (2-3)	Well	1	$180,000	$180,000
PE 5 (2-5)	Well	1	$180,000	$180,000
Pumping Equipment				
Mobilization	EA	9	$10,000	$90,000
Pump & Motor, 200 gpm Pump w/ column pipe and pitless unit	EA	9	$100,000	$900,000
Well Building & Piping	EA	9	$30,000	$270,000
Electrical Components, VFD and Telemetry & SCADA	EA	9	$92,000	$828,000
Miscellaneous Costs/Testing	EA	9	$10,000	$90,000
Well Field Transmission Pipeline System				
Transmission Main; 12 inch	LF	9500	$83	$788,500
Transmission Main; 10 inch	LF	2750	$72	$198,000
Well Field Pipe; 8 inch	LF	6000	$66	$396,000
Powerlines				
Primary Line	Miles	2.3	$75,000	$172,500
Secondary Line	Miles	2.2	$50,000	$110,000
Access Roads				
Primary Road	Miles	2.5	$80,000	$200,000
Secondary Road	Miles	2	$40,000	$80,000
Subtotal 1				$5,743,000
Engineering @ 10% of Subtotal 1				$574,300
Subtotal 2				$6,317,300
Contingency @ 15% of Subtotal 2				$947,595
Total Construction Costs				$7,264,895
Surveying				$35,000
Geotechnical				$25,000
Legal Costs				$15,000
Easements				$20,000
Permitting				$50,000
Plans and Specs				$100,000
			Total Costs	**$7,509,895**

Note: Costs are based on 2012 dollars

1 - Includes costs to complete wells with screen and gravel pack.

4.0 Recommendations

Based on the results of the Belvoir Ranch Groundwater Level II Study, the project team offers these recommendations for the WWDC and the BOPU related to the development of the Casper Aquifer on the west end of the Ranch.

- ✓ Obtain additional hydrologic and hydrogeologic data as follows to understand how the Casper Aquifer can be sustainably developed:
    - o Install data logging pressure transducers in all six Casper Aquifer test wells to record water level and temperature data six times daily year round; estimated cost, $20,000.
    - o Install stream gaging stations equipped with data logging pressure transducers up and downstream of the sinks on Lone Tree, Goose, and Duck Creeks to record streamflow six times daily year round; estimated cost, $75,000.
    - o Construct a gaging station on Granite Springs to record spring discharge six times daily year round; estimated cost, $15,000.
    - o Based on well, stream, and spring discharge data, assess the volume of water that recharges the aquifer on an annual basis, and evaluate how recharge conditions affect water levels in the aquifer and potential changes in aquifer storage.
- ✓ Conduct further exploration and test well drilling of the Casper Aquifer in the various well fields in advance of production well completion and full scale development:
    - o Obtain additional local seismic reflection and CSAMT geophysical data to better tie together the geologic and hydrogeologic framework of the aquifer in this area and refine well site locations and drilling depths; and
    - o Conduct further test production well drilling at sites identified from the geophysical and geologic exploration.
- ✓ Complete production wells prior to constructing pipeline or associated infrastructure at either identified well field:
    - o Complete production wells without screen and gravel pack at the Lone Tree Creek Well Field first;
    - o Finish successful production wells at Lone Tree Creek with screen and gravel pack;
    - o Complete production wells without screen and gravel pack at the Duck Creek Well Field; and
    - o Finish successful production wells at Duck Creek with screen and gravel pack.