EXECUTIVE SUMMARY

Greybull Wells Rehabilitation
Level II Study

Well Evaluation, Rehabilitation, and Testing
Greybull Water Transmission Pipeline Evaluation
Well Siting Study

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Submitted to:
Wyoming Water Development Commission
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Christopher G. Moody

I, Murray T. Schroeder, a Wyoming registered Professional Engineer, certify that this Greybull Wells Rehabilitation, Level II, Study was prepared by me or under my direct supervision.

Murray T. Schroeder
EXECUTIVE SUMMARY

ES.1 Introduction

The Greybull Wells Rehabilitation, Level II, Study was sponsored by the Town of Greybull, Wyoming, and funded by the Wyoming Water Development Commission. The initial and expanded objectives of the study included:

- Enhance the Town’s water supply by the rehabilitation of the Greybull #1 and Shell #3 wells
- Investigate the feasibility of pumping systems in the Shell #3 and Shell #1 wells
- Evaluate the physical condition and hydraulic capabilities of the Greybull Water Transmission Pipeline (GWTP)
- Provide conceptual designs and cost estimates for water supply enhancement project.
- Perform a municipal well siting study

ES.2 Greybull Water Supply System

The Town of Greybull obtains water supplies from three flowing artesian wells completed in the Madison-Bighorn aquifer: Shell #1, Shell #2, and Shell #3. Figure ES-1 shows the study area and the location of municipal wells, storage tanks, and the 16.5 mile GWTP. Greybull experiences water supply shortages and implements water rationing during the summer.

ES.3 Greybull #1

The Greybull #1 well is located 9 miles east of Greybull adjacent to the Whaley Cemetery. Drilled in January 1983 to a depth of 3,238 feet, the well was intended to supplement municipal supplies. The well was not incorporated into the municipal water system because of inadequate artesian flow (85 gpm) and poor water quality.

The intended well design was to set casing to the top of the Madison Limestone and to proceed with open hole through the Madison-Bighorn aquifer. The bottom of casing was actually set at the top of the Tensleep Sandstone and the open hole penetrates...
the Tensleep Sandstone, Amsden Formation, and the Madison Limestone. After February 1983, a portion of the open hole collapsed and the depth of the well is now 2,560 feet. A blockage exists adjacent to the upper portion of the Amsden Formation and the well is open to 29 feet of the Amsden and 103 feet of the Tensleep Sandstone. Flow from the Madison Limestone has been effectively sealed-off. The well has an artesian pressure of about 200 psi, artesian flow of about 12 gpm, and a total dissolved solids concentration of 2,540 mg/L that is representative of water quality from the Tensleep Sandstone.

At Greybull #1 the Madison Limestone has exceptionally poor permeability. Given the lack of mapped geologic structure near the well, chances are that permeability of the Bighorn Dolomite will also be poor. Recompletion of Greybull #1 will be an expensive and risky endeavor whose success will depend on the open hole stability of the Jefferson Formation, a fortuitous encounter with adequate fracture permeability in the Bighorn Dolomite, and/or a successful acid-frac stimulation that connects the well to high permeability fracture networks in the Madison Limestone and/or Bighorn Dolomite.

ES.4 Shell #3

Shell #3 was drilled in 1996 and put on-line in October 2000 to supplement water supplies from Shell #1 and Shell #2. Shell #3 was completed in 1996 to a total depth of 2,061 feet and consisted of an open hole completion in the Madison Limestone, Jefferson Formation, and Bighorn Dolomite. The open hole portion of the well has subsequently collapsed in the middle/lower portion of the Jefferson Formation and has may have sealed-off the Bighorn Dolomite. The objective of Shell #3 rehabilitation was to remove the downhole blockage, determine the likely cause for flow and pressure declines, and attempt to increase artesian flow using methods that would not compromise the well.

A packer test confirmed that there were no compromises in the casing that could explain the decline in shut-in pressure after the acid-frac in 1997. A drill rig was mobilized over the well to drill through the blockage and clean-out the open hole. The blockage could not be removed due to extremely unstable conditions in the Jefferson Formation. The inability to open the hole to the Bighorn Dolomite prevented an unequivocal evaluation of the production and pressure contributions to the well from the
Bighorn Dolomite. Wyoming Groundwater believes that the Bighorn Dolomite probably does not contribute a significant amount of artesian flow and that the pressure decline observed after the acid-frac is not a result of the blockage.

The lower portion of the casing was shot perforated from 1,002 to 1,045 feet in an attempt to obtain additional production from the Madison Limestone. The effect of shot perforation on artesian flow is inconclusive.

A downhole camera survey was performed which indicated that casing and joints appear to be in good condition, that 1,053 to 1,147 feet in the Madison Limestone has open voids (karst) and fractures (especially a horizontal fracture at 1,147 feet with aggressive flow to the well), and that the thinly bedded grey shale/siltstone in the lower Jefferson Formation is very unstable.

A 7-day constant rate pump test demonstrated that Shell #3 can produce 450 gpm with a depth to water during pumping of approximately 310 feet. The rate of drawdown declined noticeably (i.e., positive boundary) during pumping that will help stabilize water levels during periods of extended pumping. The calculated specific capacity of Shell #3 is 1.0 gpm per foot of drawdown.

As a result of well rehabilitation, long-term artesian flow from Shell #3 has been increased by about 25 gpm. The anticipated rate of artesian flow to the storage tank should range from 125 to 150 gpm. The installation of a pumping system at Shell #3 can provide at least an additional 300 gpm from present day artesian production.

ES.5 Shell #1

The Level II study objective at Shell #1 and Shell #2 was to conduct a pump test at Shell #1 and determine the magnitude of hydraulic interference and subsequent reduction of artesian flow at nearby Shell #2. A 7-day constant rate pump test demonstrated that Shell #1 can be pumped at a rate of 450 gpm with a depth to water of approximately 300 feet. Negative boundaries conditions that can cause accelerated drawdown were not encountered.

The increase in production obtained from pumping Shell #1 will be offset by the loss of artesian flow from the Shell #1 and Shell #2 wells. Pumping 450 gpm from Shell #1 is offset by a loss of 180 gpm artesian flow from Shell #1 and 78 gpm artesian flow.
from Shell #2. Over a 7-day period of pumping Shell #1 at a rate of 450 gpm, the total net gain in production from the Shell #1/Shell #2 system will be approximately 190 gpm (i.e., 450 gpm – 180 gpm – 78 gpm). Pumping continuously over longer time periods would cause additional declines of artesian flow from Shell #2.

ES.6 Wellfield Production

In 2004, artesian flow from Shell #3 and Shell #1/#2 provided approximately 17% and 83% of the total water supply, respectively. Shell #3 was operated continuously in 2004 and provided an average production of 117 gpm. Well rehabilitation efforts have increased the artesian flow to approximately 140 gpm. In the summer months, the Shell #1/#2 wells are open (flowing) between 50% to 98% of the time and production from a typical flow cycle gradually declined from 1,140 gpm in the spring, to a low of 920 gpm by mid-August.

The instantaneous combined production from Shell #1 and Shell #2 depends on the frequency and duration of flow cycles. When the aquifer is allowed to recover (i.e., shut-in/closed valve) during the winter, the instantaneous production is about 1,240 gpm; whereas sustained frequent flow cycles during the summer cause lower instantaneous production on the order of 950 gpm. Larger instantaneous flows from Shell #3 are also possible when the well is shut-in and the aquifer allowed to recover.

Pumping systems in Shell #3 and Shell #1 can provide a total supply on the order of 1,770 gpm in the winter and 1,610 gpm in the summer. These estimates are based on a pump capacity of 450 gpm and current well performance and operation. Pumping systems will provide more operational flexibility to meet demands and the opportunity for wells/aquifer to recover seasonally.

ES.7 Water Supply and Demand

The current sustainable capacity of the wells includes Shell #1 at 180 gpm, Shell #2 at 950 gpm, and Shell #3 at 150 gpm for a total of 1,280 gpm. The planning horizon (2030) maximum day demand (MDD) is 1,700 gpm. Therefore, the required future supply enhancement is a minimum of 420 gpm. With the largest well out of service, in 2030, the other two wells should be capable of providing the 565 gpm average daily
demand (ADD). The ADD currently, in 2006, is approximately 475 gpm. The current and planning horizon ADD well production requirements are not satisfied because the combined artesian production from Shell #1 and Shell #3 is about 320 gpm. Based on current and projected MDD and ADD values, and WDEQ well production requirements, the existing supply needs to be supplemented.

Currently, Greybull obtains water exclusively from three flowing artesian wells that can provide 1,120 to 1,280 gpm in the summer and winter, respectively. The installation of pumps in Shell #1 and Shell #3 could expand the supply to 1,610 to 1,770 gpm in the summer and winter, respectively. Pumping systems will get Greybull very close to satisfying the projected (year 2030) maximum daily demand of 1,700 gpm and will alleviate current summer-time water supply shortages. The estimated summer time (i.e., period of maximum daily demand) production capacity with pumps is 1,610 gpm.

The installation of pumping systems appears to be a feasible enhancement to Greybull’s water supply and is very close to satisfying projected demands to the year 2030. The availability and use of water (both short-term and long-term) from the Big Horn Regional Water System will provide supply redundancy in the event of emergencies (e.g., pipeline or well failure) and unforeseen increases in demand.

ES.8 Greybull Water Transmission Pipeline Evaluation

The potential to acquire additional water supplies from pumping systems at Shell #3 and Shell #1 initiated an assessment of the physical condition of the asbestos cement (AC) pipeline and an evaluation of the hydraulic capability of the Greybull Water Transmission Pipeline (GWTP).

The GWTP pipeline was originally installed in the late 1930’s as a steel pipeline from the infiltration gallery in Shell Creek to the Town of Greybull. Due to corrosion, portions of the line were replaced with 12-inch diameter AC pipeline in the 1960’s. These spot replacement efforts used 150 psi working pressure class pipe. In 1973, a pipeline replacement project was completed that replaced the remaining steel sections with 14-inch diameter AC pipe. The replacement segments were pressure Class T40, T45, and T60 pipe. Most of the 14-inch diameter pipe is Class T40, except portions of the line in Scharen Gulch, West Scharen, and near the 1 MG storage tank. In 1986, the
Shell #1 and Shell #2 wells were connected to the GWTP using 12-inch diameter PVC pipe. In 1997, the Shell Creek infiltration gallery was abandoned and the Shell #3 well was brought on-line. Pressure reducing (PRV) and sustaining (PSV) valves were installed along the pipeline in the late 1990’s.

The flow test of the pipeline reach between the Lucas PRV station and the Dog Pound (near the 1 MG storage tank) provided a C value of 135. This value compares well with published values for AC pipe and indicates that the internal condition of the pipeline is not tuberculated or otherwise rougher than AC pipe of new manufacture. This C value was used in subsequent hydraulic modeling efforts.

The purpose of the hydraulic evaluation of the GWTP was to:

- Estimate the pipeline’s existing capacity to deliver water as it was presently being operated;
- Evaluate operational and physical improvements (i.e., a conceptual design) that would allow the GWTP to deliver the required flow to the 1 MG storage tank;
- Provide information (e.g., static and transient pipeline pressures) for the structural evaluation of the pipeline; and
- Determine if additional production from the Shell #1 and Shell #3 wells could be delivered to Greybull without adverse consequences to the pipeline system or Shell Valley users along the line.

Figure ES-2 is a plan and profile drawing of the GWTP and presents the results of the hydraulic evaluation. Water supply objectives can be achieved with relatively minor modifications to the existing pressure control valves in the GWTP. Figure ES-3 shows proposed conceptual design modifications along the GWTP.

Any proposed changes in the operational pressures and flow conditions in the GWTP must occur within pipeline design specifications and risk factors based on the present day condition of the pipeline. The GWTP was exposed at ten locations shown on Figure ES-4. External pipeline inspection consisted of the visual observation of the pipe exterior and soil in the trench, collection of soil and groundwater samples, and Ultrasonic Pulse Velocity (UPV) and Schmidt hammer nondestructive tests. Samples of AC pipe for
petrographic analysis were obtained by tapping the pipe at six of the ten excavations, plus a sample from a piece of pipe found in the excavation near the Highway 14 crossing. Mechanical testing was performed on pipe samples obtained from an abandoned portion of the pipeline west of the infiltration gallery (Excavation #12). Samples obtained for petrographic analysis and mechanical testing included all known pipe classes along the GWTP between the supply wells and the 1 MG storage tank.

Based on the results of exterior inspection, material testing, petrographic and chemical analysis, hydraulic analysis, and pipe structural evaluation, the following conclusions are presented regarding the condition and future use of the GWTP.

- Overall composition and microstructure of the asbestos cement is very good and there is no systematic deterioration of the AC pipe.
- There was no evidence of sulfate attack and only minor to moderate acid attack at sporatic locations. However, owing to the limited sampled size, it is possible that there may be isolated pipes or areas with worse deterioration than observed.
- There the failure rate and reliability of the GWTP will continue to be lower than for other similar AC pipelines.
- The GWTP is safe to operate under existing working pressures. Valve closure at the 1 MG tank may result in high pressures and cause damage to the pipeline and should be avoided prior to modification of pipeline valves.
- The GWTP may be operated under the proposed future flow condition after modifications of the PRV/PSV’s to maintain the maximum pressure in the line below 145 psi, but with reduced safety. Undeteriorated pipes will have a factor of safety approximately equal to that recommended by AWWA C403.
- Water in the pipeline is not corrosive to AC pipe, no asbestos fibers were detected in water from the pipeline, and no internal deterioration of the pipe as been observed.
The results of physical condition assessment and hydraulic modeling indicate that use of the existing GWTP, with modification to existing pipeline valves and pipeline operation, is a viable option to obtain additional water supplies capable of satisfying current and future water demands.

**ES.9 Well Siting Study**

Four municipal water well prospects in the Madison-Bighorn aquifer were identified in the vicinity of Greybull. The highest ranked prospect, North Cherry Anticline, is located 5.3 miles east of Greybull along State Highway 14. It is anticipated that the well siting study will be used to assist the Big Horn Regional Water Supply System in the exploration and development of groundwater resources at the north end of the regional water system.

**ES.10 Economics and Financing**

The least expensive alternative (as defined by the estimated increase in average monthly service charge to Greybull water system customers) to obtain adequate water supplies to the year 2030 is the installation of pumps in the Shell #3 and Shell #1 wells, and making minor modifications and improvements to the GWTP.

Assuming a maximum 75% grant and 25% loan scenario, pumping systems and GWTP improvements together are estimated to result in an increase in monthly service charge of approximately $1.03.

**ES.11 Recommendations**

The Level II study project team recommends that the Town of Greybull should:

1. Attempt to find someone willing to assume ownership of Greybull #1, and if unsuccessful, the well should be plugged and abandoned.
2. Not attempt any future efforts to remove the blockage in Shell #3.
3. Install pumping systems in Shell #1 and Shell #3; each well with a capacity to pump at least 450 gpm.
4. Modify the existing pressure control valves and system operation as described in the conceptual designs of this report.
5. Make improvements to the telemetry system to reduce operational difficulty and increase system reliability.

6. Control the maximum surge pressure in the pipeline to reduce the risk of pipeline failure.

7. Collect future tap samples and perform petrographic analysis of samples to supplement the results of this pipeline evaluation study and determine if there are areas with more degradation than observed thus far.

8. Re-evaluate the condition of the pipeline within the next ten years based on distress observed on future tap samples and actual hydraulic transient pressures.

9. Develop an operations manual to establish procedures for valve operation to minimize transient pressures and establish procedure for tapping and analysis of tap samples.

10. Defer groundwater development efforts involving the exploration and installation of high yield wells in the Madison-Bighorn aquifer to the Big Horn Regional Water System. This recommendation assumes that the Town installs pumping systems in Shell #1 and Shell #3.

11. Apply to the WWDC for Level III funding to install pumping systems and make GWTP improvements.
CONCEPTUAL DESIGN
MODIFICATIONS AND IMPROVEMENTS TO THE GREYBULL WATER TRANSMISSION PIPELINE

FIGURE ES-3

- Retrofit existing valve to modulate and provide constant tank level
- Replace existing 8-inch valve with 4-inch valve with flow control functionality and PR/PSV.
- Install pressure relief and bypass piping
- Install bypass PRV/PSV for main valve service
- Operate main line valves as PRVs with PSV backup

REPLACE EXISTING 8-INCH VALVE WITH 4-INCH VALVE WITH FLOW CONTROL FUNCTIONALITY AND PR/PSV.

MAKE MODEST TELEMETRY IMPROVEMENTS TO IMPROVE SYSTEM RELIABILITY.

ABANDONED INFILTRATION GALLERY (SHELL CREEK)

SHELL #3 WELL AND 0.10 MG TANK

SHELL 0.35 MG TANK

SHELL #2 WELL

SHELL #1 WELL

LEGEND
- LUCAS PSV
- DOG POUND PRV/PSV
- GREYBULL WATER TRANSMISSION PIPELINE (GWTP)
- GREYBULL #1 WELL
- WHALLEY PRV/PSV
- SMITH VALVE
- TWO BIT PRV/PSV

SCALE 0 7000
<table>
<thead>
<tr>
<th>Soil Chemistry and Physical Properties&lt;sup&gt;(1)&lt;/sup&gt;</th>
<th>Chugwater formation, red shale with occasional gypsum</th>
<th>Gypsum Spring Formation&lt;sup&gt;(1)&lt;/sup&gt;</th>
<th>Corrosive soil</th>
<th>Alkali Deposits, Cloverly/Thermal contact</th>
<th>Massive gyspum in sediments with abundant alkali surface deposits. Potentially expansive soil. Presence of gyspum in overlying Tertiary Shale.</th>
</tr>
</thead>
<tbody>
<tr>
<td>High groundwater, flood-irrigated fields, extensive irrigation leachates.</td>
<td>High groundwater, heavy infiltration.</td>
<td>High groundwater, heay infiltration.</td>
<td>Fields off Whaley Ditch, diked ground</td>
<td>Section of drainage abandoned.</td>
<td>Shallow groundwater, section of drainage abandoned.</td>
</tr>
<tr>
<td>Steinly sand, gravel, some silt.</td>
<td>Sandy, fine grained sand and gravel.</td>
<td>Sandy, fine grained sand and gravel.</td>
<td>Fine gravelly loam.</td>
<td>Sandy, loamy sand.</td>
<td>Sandy, loamy sand.</td>
</tr>
<tr>
<td>Granite, sand, gravel, some silt.</td>
<td>Sandy, fine grained sand and gravel.</td>
<td>sandy, fine grained sand and gravel.</td>
<td>Fine gravelly loam.</td>
<td>Sandy, loamy sand.</td>
<td>Sandy, loamy sand.</td>
</tr>
<tr>
<td>Ground Water Yes, No, No, dry Yes, No, dry, Yes, No, dry.</td>
<td>No.</td>
<td>No, dry.</td>
<td>Yes, No, dry.</td>
<td>No, dry.</td>
<td>No, dry.</td>
</tr>
<tr>
<td>Soil/Water Sulfate (mg/kg/mg/L)</td>
<td>146/153, 59/-, 39/-, 97/34, 14,300/-, 20,200/13,700.</td>
<td>-/-, 14,300/20,200.</td>
<td>-/-, 20,200/-, 13,700/-, 6,270/-, 25,100/37,500.</td>
<td>19,200/10,200, 28,600/-, 37,500/-, 10,200/28,600.</td>
<td></td>
</tr>
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<td>Schmidt Hammer Test - 33.2, 36.2, 44.2, 38, 40.2.</td>
<td>- 38.3, 40.3, 35.8, 35.8.</td>
<td>-/-, 50.3, 35.8, 35.8, 35.8.</td>
<td>-/-, 50.3, 35.8, 35.8, 35.8.</td>
<td>-/-, 50.3, 35.8, 35.8, 35.8.</td>
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<tr>
<td>Ultrasonic Test - 72.8, 73.3, 71.6, 71.1, 70.5.</td>
<td>- 71.9, 70.6, 72.4, 72.4, 72.4.</td>
<td>-/-, 71.9, 70.6, 72.4, 72.4, 72.4.</td>
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<td>-/-, 71.9, 70.6, 72.4, 72.4, 72.4.</td>
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<td>P&lt;sub&gt;design&lt;/sub&gt; 0.26, 0.41, 0.56, 0.63, 0.78, 0.64.</td>
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<td>0.38, 0.30, 0.16, 0.02, 0.04, 0.04.</td>
<td>0.38, 0.30, 0.16, 0.02, 0.04, 0.04.</td>
<td>0.38, 0.30, 0.16, 0.02, 0.04, 0.04.</td>
<td></td>
</tr>
</tbody>
</table>

<sup>(1)</sup> Areas where pipe lies in water (shallow groundwater).

<sup>(8)</sup> Areas of proposed and existing highest operating pressure in the pipe.

<sup>(9)</sup> P<sub>design</sub> is 150psi working pressure with S.F. = 4, and for T40 & T45 assume P<sub>design</sub> is 1/4 the design pressure of 400psi and 450psi, respectively.

<sup>(10)</sup> Areas where pipe lies in water (shallow groundwater).