Greybull Wells Rehabilitation
Level II, Study

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

Volume I of II

November 1, 2006

Submitted to:
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Murray T. Schroeder
# TABLE OF CONTENTS

**GREYBULL WELLS REHABILITATION, LEVEL II STUDY**

**VOLUME I OF II**

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXECUTIVE SUMMARY</td>
</tr>
<tr>
<td><strong>CHAPTER 1</strong> INTRODUCTION</td>
</tr>
<tr>
<td>1.1 Background</td>
</tr>
<tr>
<td>1.2 Project Objectives</td>
</tr>
<tr>
<td>1.3 Scope of Work</td>
</tr>
<tr>
<td>1.4 Report Organization</td>
</tr>
<tr>
<td>1.5 Acknowledgements</td>
</tr>
<tr>
<td><strong>LIST OF FIGURES</strong></td>
</tr>
<tr>
<td>Figure 1-1 Study Area</td>
</tr>
<tr>
<td><strong>CHAPTER 2</strong> GREYBULL #1 WELL</td>
</tr>
<tr>
<td>2.1 Background</td>
</tr>
<tr>
<td>2.2 Greybull #1 Well History and Condition</td>
</tr>
<tr>
<td>2.3 Discussion of Greybull #1 Well Options</td>
</tr>
<tr>
<td>2.3.1 Well Recompletion</td>
</tr>
<tr>
<td>2.3.2 Transfer Well Ownership</td>
</tr>
<tr>
<td>2.3.3 Plug and Abandon Greybull #1 Well</td>
</tr>
<tr>
<td>2.4 Recommendations for Greybull #1 Well</td>
</tr>
<tr>
<td><strong>LIST OF TABLES</strong></td>
</tr>
<tr>
<td>Table 2-1 Water Quality Data from Greybull #1 Well</td>
</tr>
<tr>
<td><strong>LIST OF FIGURES</strong></td>
</tr>
<tr>
<td>Figure 2-1 Existing Condition of Greybull #1</td>
</tr>
<tr>
<td>Figure 2-2 Proposed Design for Plugging and Abandonment Greybull #1</td>
</tr>
<tr>
<td><strong>CHAPTER 3</strong> SHELL #3 WELL</td>
</tr>
<tr>
<td>3.1 Shell #3 Well Construction and History</td>
</tr>
<tr>
<td>3.2 Shell #3 Well Rehabilitation</td>
</tr>
<tr>
<td>3.2.1 Permits and Access Agreements</td>
</tr>
<tr>
<td>3.2.2 Pre-Rehabilitation Artesian Flow Test</td>
</tr>
</tbody>
</table>
3.2.3 Casing Integrity Test .................................................. 3-4
3.2.4 Well Clean-Out ......................................................... 3-4
3.2.5 Geophysical Logging .................................................. 3-5
3.2.6 Shot Perforation ......................................................... 3-6
3.2.7 Down hole Camera Survey ........................................... 3-6

3.3 Results of Pump Tests at Shell #3 .................................... 3-7
3.3.1 Shell #3 Step Test ..................................................... 3-8
3.3.2 Shell #3 Pump Test at 400 gpm ....................................... 3-8
3.3.3 Shell #3 Pump Test at 450 gpm ....................................... 3-8
3.3.4 Water Quality .......................................................... 3-10

3.4 Post-Rehabilitation Artesian Flow Test and Observations ........ 3-11
3.5 Summary of Shell #3 Rehabilitation and Testing ..................... 3-11

LIST OF TABLES

Table 3-1 Pre-Acid Frac and Post-Acid Frac Well Production and Pressures at Shell #3 .................. 3-13
Table 3-2 Results of Shell #3 Pre-Rehabilitation and Post-Rehabilitation Constant Drawdown (Pressure) Flow Tests .................................................. 3-14
Table 3-3 Summary of Geophysical Log Evaluation of the Madison Limestone in Shell #3 .................. 3-15
Table 3-4 Artesian Flow and Wellhead Pressure Measurements at Shell #3 During Field Work ........ 3-16
Table 3-5 Water Quality Analyses from Shell #3 ................................ 3-17

LIST OF FIGURES

Figure 3-1 Shell #3 Well Condition, April 2005 ......................................... 3-18
Figure 3-2 Shell #3 Time-Drawdown Data, 450 gpm Pump Test .................. 3-19
Figure 3-3 Shell #3 Recovery Data, 450 gpm Pump Test ......................... 3-20

CHAPTER 4 SHELL #1 WELL

4.1 Background .................................................................... 4-1
4.2 Objectives and Approach ................................................ 4-3
4.3 Permits and Access Agreements ....................................... 4-3
4.4 Pre-Pump Test Conditions .............................................. 4-3
4.5 Results of Pump Tests at Shell #1 .................................... 4-4
4.5.1 Shell #1 Step Test ...................................................... 4-5
4.5.2 Shell #1 Pump Test at 450 gpm – Shell #1 ....................... 4-5
4.5.3 Shell #1 Pump Test at 450 gpm – Shell #2 ....................... 4-7
4.5.4 Potential Gain in Production at the Shell (Trapper) Wells ............ 4-8
4.5.5 Water Quality .......................................................... 4-8
4.6 Shell #1 Down hole Camera Survey ................................... 4-9
4.7 Summary of Shell #1 Testing ............................................ 4-9
LIST OF TABLES

Table 4-1 Artesian Flow Data from Shell #2 during Shell #1 Pump Test 4-11
Table 4-2 Water Quality Analysis from Shell #1 4-12

LIST OF FIGURES

Figure 4-1 Shell #1/Shell #2 Well Diagrams 4-13
Figure 4-2 Shell #1 and Shell #2 Operation Cycle, April 14, 2005 4-14
Figure 4-3 Shell #1 Wellhead Pressure with Shell #1 Shut-In
And Shell #2 Flowing at 970 gpm 4-15
Figure 4-4 Shell #2 Wellhead Pressure with Shell #1 Shut-In
And Shell #2 Flowing at 970 gpm 4-16
Figure 4-5 Shell #1 Time-Drawdown Data, 450 gpm Pump Test 4-17
Figure 4-6 Shell #2 Wellhead Pressure during 450 gpm Pump Test 4-18
Figure 4-7 Maximum Wellhead Pressure at Shell #2 During
450 gpm Pump Test 4-19
Figure 4-8 Shell #2 Average Artesian Flow During 450 gpm Pump Test 4-20
Figure 4-9 Shell #2 Artesian Flow Decline During 450 gpm Pump Test 4-21

CHAPTER 5 WELLFIELD OPERATION AND PERFORMANCE

5.1 Operation and Performance of Shell #3 5-1
5.2 Operation and Performance of Shell #1 and Shell #2 5-2
5.3 Anticipated Production with Pumping Systems 5-3

LIST OF TABLES

Table 5-1 Reported and Measured Shut-In Pressures at Shell #1 and Shell #2 5-4
Table 5-2 Comparison of Current Artesian Production with Estimated Pump System Production 5-5

LIST OF FIGURES

Figure 5-1 2004 Monthly Well Production 5-6

CHAPTER 6 WATER DEMAND AND SUPPLY

6.1 Introduction 6-1
6.2 Population Forecast 6-1
6.3 Water Demand 6-2
6.4 Water Supply Needs Analysis 6-3
6.5 Water Supply Summary 6-3
CHAPTER 7 GREYBULL WATER TRANSMISSION PIPELINE EVALUATION

7.1 Introduction .................................................. 7-1
7.2 GWTP History and Operation .................................. 7-1
7.3 Pipeline Flow Test ............................................. 7-3
7.4 Leak Detection Testing ........................................ 7-3
7.5 Valve Inspection and Discussions with System Operator  ....... 7-4
7.6 Pipeline Location and Elevation Survey ........................ 7-4
7.7 Service Connection Mapping .................................. 7-4
7.8 Pipeline Hydraulic Evaluation .................................... 7-5
   7.8.1 Existing GWTP Conditions ................................. 7-6
   7.8.2 Conceptual Design for Future GWTP Conditions ......... 7-6
   7.8.3 Hydraulic Evaluation to Support Structural Evaluation .. 7-7
7.9 Pipeline Material Inspection, Testing, and Evaluation ........... 7-7
   7.9.1 Historical Performance of GWTP .......................... 7-8
   7.9.2 Pipe Inspection ............................................. 7-9
   7.9.3 Pipeline Material Testing ................................... 7-10
   7.9.4 Hydraulic Analysis ......................................... 7-12
   7.9.5 Structural Evaluation ....................................... 7-12
7.10 Conclusions and Recommendations on GWTP Condition and  
     Future Use .................................................... 7-14
7.11 Service Connection Pressures .................................. 7-15
7.12 Summary ...................................................... 7-16

LIST OF TABLES

Table 7-1 Greybull Water Transmission Pipeline Excavation Data .......... 7-17

LIST OF FIGURES

Figure 7-1 Pipeline Excavation Locations ..................................... 7-18

LIST OF PLATES

Plate 7-1 Hydraulic Grade Lines, Greybull Water Transmission Pipeline

CHAPTER 8 WELL SITING STUDY

8.1 Purpose of Well Siting Study ..................................... 8-1
8.2 Study Area .................................................... 8-1
LIST OF TABLES
Table 8-1 Inventory of Wells Completed in Madison-Bighorn Aquifer
Table 8-2 Water Well Prospect Ranking

LIST OF FIGURES
Figure 8-1 Hydrostratigraphy in the Vicinity of Greybull

LIST OF PLATES
Plate 8-1 Principal Tectonic Structures in Vicinity of Greybull
Plate 8-2 Lineament Map
Plate 8-3 Municipal Water Well Prospects in Vicinity of Greybull

CHAPTER 9 CONCEPTUAL DESIGNS AND COST ESTIMATES
9.1 Introduction
9.2 Draft Report Alternatives
9.3 Pumping Systems in Shell #1 and Shell #3
9.4 Modifications and Improvements to the GWTP
9.5 Project Integration and Cost Estimate
9.6 New Well at North Cherry Anticline Prospect
9.7 Environmental Report
9.8 Discussion
LIST OF TABLES

Table 9-1  Cost Estimate for Pumping Systems in Shell #3 and Shell #1  9-8
Table 9-2  Cost Estimate for GWTP Valve and Telemetry System Improvements  9-9
Table 9-3  Cost Estimate for North Cherry Anticline Well  9-10

LIST OF FIGURES

Figure 9-1  Conceptual Design for Pumping Systems in Shell #1 and Shell #3  9-11
Figure 9-2a  Conceptual Design Modifications and Improvements to the GWTP  9-12
Figure 9-2b  Conceptual Design Pressure Relief and PRV/PSV By-Pass  9-13
Figure 9-3  Conceptual Design North Cherry Anticline Well Construction  9-14
Figure 9-4  Conceptual Design North Cherry Anticline Prospect  9-15

CHAPTER 10  FINANCING

10.1  Introduction  10-1
10.2  Draft Report Alternative Financing  10-1
10.3  Financing Resources  10-1
  10.3.1  Wyoming Water Development Commission  10-1
  10.3.2  County Capital Facilities Tax  10-2
  10.3.3  USDA Rural Development – Rural Utilities Service  10-2
  10.3.4  Wyoming State Land and Investment Board  10-3
  10.3.5  State Revolving Fund  10-3
10.4  Financing Assumptions  10-3
10.5  Financing Summary  10-4

LIST OF TABLES

Table 10-1  Annual Operations and Maintenance Budget  10-5
Table 10-2  Project Financing Summary  10-6

CHAPTER 11  CONCLUSIONS AND RECOMMENDATIONS

11.1  Conclusions  11-1
11.2  Recommendations  11-3

REFERENCES CITED  R-1
VOLUME II OF II
LIST OF APPENDICES

Appendix A – Greybull #1 Supporting Documents
Appendix B – Shell #3 Supporting Documents
Appendix C – Shell #1 and Shell #2 Supporting Documents
Appendix D – Wellfield Production Data Tables
Appendix E – Pipeline Evaluation Supporting Documents
Appendix F – Well Siting Supporting Documents
Appendix G – Financing Supporting Documents
EXECUTIVE SUMMARY

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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

ES-2
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
decreased 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 sporadic 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.
FIGURE ES-1
Study Area with Municipal Wells, Storage Tanks, and Transmission Pipeline

Greybull Wells Rehabilitation, Level II, Study

WYOMING GROUNDWATER, LLC
CONCEPTUAL DESIGN
MODIFICATIONS AND IMPROVEMENTS TO THE GREYBULL WATER TRANSMISSION PIPELINE

FIGURE ES-3

- Refurbish existing hydraulic valves
- Install pressure relief and bypass piping
- Install bypass PRV/PSV for main valve service
- Operate main line valves as PRVs with PSV backup

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/PS.

Greybull #1 well

Whalley PRV/PSV

Lucas PSV

Greybull Water Transmission Pipeline (GWTP)

Dog Pound PRV/PSV

Greybull 1.0 MG Tank

Open existing gate valve

Greybull #2 well

Smith valve

Greybull #1 well

Shell 0.35 MG Tank

Shells (Shell Creek)

Abandoned Infiltration Gallery

Shells #2 well

Shells #3 well

AND 0.10 MG Tank

Make modest telemetry improvements to improve system reliability.
<table>
<thead>
<tr>
<th>Excavation Name</th>
<th>Information</th>
<th>Iowa State-Camp</th>
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<th>Woodland</th>
<th>West White</th>
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**Soil Chemistry and Physical Properties**

- Chugwater formation, red shale with occasional gypsum
- Gypsum Spring Formation
- Corrosive soil
- Massive grey shale in intersection with abundant alkali surface deposits
- Potentially expansive soil
- Bentonite in Thermop Shale

**Water Saturation**

- Sand, fine gravelly, and silt
- Sandy, fine grained
- Clayey in trench, sand and gravel native and below
- Sandy fine grained, clayey
- Clayey, silty shale
- Broken rock fragments

**Soil/Observations**

- Granular, sand, gravel, and silt
- Sandy, fine grained
- Fine sand
- Clayey in trench, sand and gravel
- Clayey in trench, sand and gravel

**Ground Water**

- Yes
- No
- No, dry
- Yes
- No, dry
- No, dry
- No, dry
- No, dry

**Soil/Water Sulfate**

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<tr>
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<th>(mg/L)</th>
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**Schmidt Hammer Test**

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**Ultrasonic Test**

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</table>

**Other**

- Intersection of 14 in. from infiltration gallery to new 8" PVS; Shell #2, Scheben #2, Scheben #4, Shell #1, Scheben #1, Scheben #2
- 5 min. tap compared with 20 min. tap
- Benign section, Cloverly (Skyes Mtn Member)
- East of blow-off; Next to 1999 pipe failure

---

**Notes:**

1. Soil chemistry conductive to AC corrosion/degradation, and physical properties such as expansive clay.
2. Areas of proposed and existing highest operating pressure in the pipe.
3. $P_{\text{design}} = 150$ psi for working pressure with $S.F. = 4$, and for T40 & T45 assume $P_{\text{design}} = 1/4$ the design pressure of 400 psi and 450 psi, respectively.
4. Areas where pipe lies in water (shallow groundwater).
CHAPTER 1
INTRODUCTION

1.1 Background
Since 1982, the Town of Greybull has sponsored numerous studies to evaluate and develop surface water and groundwater supplies for municipal use. During this period, the Town’s water supply has evolved from the exclusive use of surface water from Shell Creek, to a combined surface water/groundwater supply, to the present-day exclusive use of groundwater from three wells. The shift away from surface water supplies was due to the requirement by the EPA to treat surface water used for public water supplies. Despite these efforts, the Town experiences water supply shortages and must implement water rationing strategies in the summer months.

A water supply study by Engineering Associates (EA, 2003b) provided a cost comparison of water supply enhancement options that included the treatment of surface water from Shell Creek, a raw water system to irrigate Town parks and lawns, and the rehabilitation of existing wells. The EA study concluded that rehabilitation of the Greybull #1 and Shell #3 wells was the most cost effective option to enhance the Town’s water supply. In 2004, the Town applied for and received funding from the Wyoming Water Development Commission (WWDC) to conduct a Level II study for well rehabilitation.

Figure 1-1 shows the study area and the location of municipal supply wells, storage tanks, and the Greybull Water Transmission Pipeline (GWTP).

1.2 Project Objectives
The objective of the Greybull Wells Rehabilitation, Level II, study is to enhance the Town’s water supply by the rehabilitation of the Greybull #1 and Shell #3 wells. Greybull #1 was improperly completed and requires the installation of additional casing and deepening. Shell #3 requires further evaluation to determine the cause for declining production and methods to regain lost production. An additional objective was a well siting study to identify prospects for new high yield water well(s) in the vicinity of
Greybull. The Level II study was expanded to include pump testing of the Shell #3 and Shell #1 wells, and an evaluation of the GWTP.

1.3 Scope of Work

On June 15, 2004, Wyoming Groundwater (WG) was awarded a contract to conduct the Level II study. WG proposed that the well siting study and a review of water supply alternatives be performed first to allow the Town to consider a comprehensive list of options that could modify the scope of work. On August 9, 2004, a meeting was held between Town Council and representatives of WG and the WWDC to discuss the well siting study, well rehabilitation, and the potential benefits of pumping systems in selected municipal wells.

Based on information presented in the August 9, 2004 meeting, the Town Council approved the rehabilitation of the Greybull #1 and Shell #3 wells, and pump testing the Shell #3 and Shell #1 wells. The sequence of work would begin with the rehabilitation of Greybull #1 and Shell #3, and pump tests would follow depending on the availability of project funds. The option of installing a test well (in lieu of rehabilitating existing wells) at a location identified in the well siting study was not approved due to insufficient funds and the Town’s desire to improve production from the Greybull #1 and Shell #3 wells.

In the fall of 2004, WG proceeded with competitive bid procurement of a drilling contractor to perform rehabilitation of Greybull #1. Subsequent to selection, conflicts between WG and the drilling contractor required termination of the drilling contract. Time constraints required that the rehabilitation of Greybull #1 be postponed and that work begin with the rehabilitation of Shell #3 and pump tests at Shell #3 and Shell #1. After determining that additional water supplies were available by pumping systems, additional work was deemed necessary to evaluate the physical condition and hydraulic capabilities of the GWTP. As a result, adequate funds were not available to rehabilitate the Greybull #1 well which fell into disfavor as an alternative in consideration of the physical condition of the well and water supply enhancement options at Shell #3 and Shell #1.
The scope of work for this Level II study included the following tasks:

- Assessment of Greybull #1;
- Evaluation and rehabilitation of Shell #3;
- Artesian flow and constant rate discharge tests at Shell #3;
- Performance evaluation and constant rate discharge tests at Shell #1;
- Evaluation of hydraulic interference with Shell #2;
- Wellfield operation and performance;
- Update estimates for water supply and demand;
- Flow testing, leak detection testing, surveying, and inspection of valves along the GWTP;
- Service connection mapping;
- Hydraulic modeling of the GWTP;
- Assessment of the physical condition of the GWTP;
- Economic and financing analysis of water supply enhancement alternatives; and a
- Well siting study.

1.4 Report Organization

This report consists of two volumes. Volume I contains an executive summary and chapters that describe the methods and results of the Level II study. Volume II consists of supporting and supplemental information in Appendices A – G. Volume I is organized in chronological order of task performance and the progression of study objectives. Chapters 2, 3, and 4 describe the results of well evaluations, rehabilitation, and pump testing at Greybull #1, Shell #3, and Shell #1/Shell #2, respectively. Chapter 5 provides an overview of wellfield operation and capabilities. Chapter 6 updates the Town’s water demand and supply situation and establishes planning horizon demand estimates to the year 2030. Chapter 7 describes the results of a detailed physical and hydraulic evaluation of the GWTP. Chapter 8 is a municipal well siting study. Chapters 9 and 10 develop conceptual designs, cost estimates, and financing options for projects described in this study. And finally, Chapter 11 provides conclusions and
recommendations. Tables, figures, and plates referenced in a chapter are provided at the end of each chapter.

1.5 Acknowledgements

The cooperation and assistance provided by Ron Vanderpool, Greybull Public Works Director, and his staff was outstanding and greatly appreciated. Special recognition is merited to Frank Coy of Weston Engineering, Inc. (Upton, WY) who provided timely and competent contractor services related to well rehabilitation and pump testing. Kevin Boyce, WWDC project manager, rendered valuable support throughout the project. The cooperation of local land owners, Chuck Landers and Kincaid Reid, is also appreciated.
TABLES AND FIGURES
FIGURE 1-1
Study Area with Municipal Wells, Storage Tanks, and Transmission Pipeline

Greybull Wells Rehabilitation, Level II, Study

WYOMING GROUNDWATER, LLC
2.1 Background

The Greybull #1 well is located adjacent to the Whaley Cemetery in Section 36, T53N, R92W (9 miles east of Greybull) and is also known as the “Artesian Water Supply Well No. 1”, “Grey Well”, “Whaley Well”, and the “Cemetery Well”. Drilled in January 1983 and funded in part by the WWDC Ground Water Exploration Grant Program, the well was intended to supplement municipal surface water supplies from Shell Creek.

The well was located adjacent to the Greybull Water Transmission Pipeline (GWTP) to provide an economical tie-in to the system. At the time of well installation, it was believed that the Madison Limestone would provide adequate artesian flows, water quality, and pressure anywhere in the Shell Creek Valley west of the community of Shell and east of the Cherry Creek Anticline (John Donnell & Associates, 1982). However, the well was not incorporated into the municipal water supply because of inadequate artesian flow of approximately 85 gpm and poor water quality (685 mg/L total dissolved solids). The well permit (U.W. 62476) was cancelled in October 1983; however, the Town of Greybull owns the well and has a land ownership and access agreement with the Whaley Cemetery Association.

Greybull #1 is flowing artesian with a shut-in pressure of approximately 205 pounds per square inch (psi). The well has been shut-in and unused since 1983 and it was the desire of the Town for this Level II study to determine what value the well has to supplement the municipal water supply. In the fall of 2004, a well evaluation and rehabilitation program was developed, but was not implemented due to drilling contract conflicts. As described in the sections that follow, basic well evaluation work was performed that provide the basis of a professional opinion regarding the future value of the well. Appendix A in Volume II contains supporting documents and information regarding Greybull #1.
2.2 Greybull #1 Well History and Condition

Information on the siting, construction, and testing of the Greybull #1 well is presented in a report by Big Horn Engineering (1983). The intended well design was to set 9 5/8-inch steel casing into the top of the Madison Limestone and to proceed with 8 ¾-inch open hole through the Madison Limestone, Jefferson Formation, and Bighorn Dolomite (Figure 2-1). The target production zones were the Madison Limestone and Bighorn Dolomite that comprise the Madison-Bighorn (M-B) aquifer. The well was drilled to a total depth of 3,238 feet and the geologist log states that the well penetrated the Madison Limestone and Bighorn Dolomite. However, geophysical logs and a cuttings inspection by American Stratigraphic Company indicate that the bottom of casing was actually set at the top of the Tensleep Sandstone and that the open hole interval penetrates the Tensleep Sandstone, Amsden Formation, and 550 feet of the Madison Limestone. Greybull #1 does not penetrate the Jefferson Formation and Bighorn Dolomite. Additional analysis and discussion of well stratigraphy are provided in Nelson Engineering (1995) and Engineering Associates (2003b).

After well completion in January 1983, the well was allowed to flow continuously for 30 days. Observed conditions from January 21 to February 21, 1983, was an artesian flow rate of 85 gpm at 61 psi, a water temperature of 62°F, and a static shut-in pressure of 205 psi (Big Horn Engineering, 1983). A water quality sample was collected during this flow period (Table 2-1). Aside from the low artesian flow, the total dissolved solids (TDS) concentration of 685 mg/L was higher than is typical for the Madison Limestone in the study area. The TDS concentration at Shell #1, which is completed exclusively in the Madison Limestone, is 215 mg/L, and TDS concentrations from springs that discharge from the Madison Limestone along the Big Horn River at Sheep Mountain range from 228 to 242 mg/L (Doremus, 1986). As indicated by a geophysical log that was run to a total depth of 3,210 feet on January 21, 1983, and the consistent flow rate for the next 30 days, it can be assumed that the borehole had not yet been obstructed and that the discharge rate and water quality data from Greybull #1 represented a mixture of water from the Tensleep Sandstone, Amsden, and Madison Limestone.

After completion of well testing in February 1983, a portion of the open hole interval collapsed. As determined by a caliper log run on August 2, 2004, the bottom of
the casing is at 2,428 feet and the depth of the well is now 2,560 feet (Appendix A). The blockage is adjacent to the upper portion of the Amsden Formation such that the hole is now open to 29 feet of the Amsden and 103 feet of the Tensleep (Figure 2-1). Regionally, the Amsden is known as an unstable formation and was responsible for caving/bridging and difficult casing installation during completion of the Shell #1 well (Morrison-Maierle, 1986). An internal WWDC memo dated October 5, 1983, mentions that Greybull #1 was flowing approximately 10 gpm with 10 psi at the wellhead (Appendix A). The reduction in artesian flow from 85 gpm to 10 gpm indicates that sometime between February 21 and October 5, 1983, a portion of the borehole had collapsed thereby inhibiting artesian flow from the underlying Madison Limestone.

On August 2, 2004, Wyoming Groundwater opened the well valve and monitored artesian flow. After 4.5 hours, the measured flow rate was 11.5 gpm. This flow rate is similar to the 10 gpm measured by the WWDC in October 1983 and the 13.8 gpm flow measured in 1995 after 6.5 hours of open flow (Nelson Engineering, 1995).

In June 2004, a water sample was collected from Greybull #1 and analyzed for major cations/anions. The TDS concentration was 2,540 mg/L and the major ion chemistry of the sample is nearly identical to the chemistry of a sample collected from the well on August 30, 1988 (Table 2-1). Since 1988, the water chemistry of the artesian flow has been distinctly different than the water chemistry measured immediately after the well was completed in 1983. The 1983 water sample was a mixture of water from the Tensleep, Amsden, and Madison Limestone (i.e., pre-collapse); whereas the 1988 and 2004 samples (i.e., post-collapse) were a mixture of water from only the upper part of the Amsden and the Tensleep. As shown in Table 2-1, the major ion chemistry of the 1988 and 2004 samples are similar to the chemistry of water samples collected from a well completed in the Tensleep Sandstone in the vicinity of Shell (Jarvis, 1986). The borehole collapse and blockage at 2,560 feet has effectively sealed off the Madison Limestone in the well.

Chemical mass balance calculations were used to substantiate the conclusion that the 1983 sample was a mixture of water from the Tensleep, Amsden, and Madison Limestone (Appendix A). Assuming that the Madison Limestone flow was approximately 73 gpm with a typical Madison TDS concentration of 215 mg/L, and an
upper Amsden/Tensleep flow of 12 gpm with a TDS concentration of 2,540 mg/L, the
1983 mixture would have a calculated TDS of approximately 547 mg/L. The calculated
mixture TDS value of 547 mg/L is reasonably close to the measured mixture TDS value
of 685 mg/L. The higher TDS value measured in 1983 was probably caused by an
additional contribution of high TDS water from the middle and lower portion of the
Amsden that is presently sealed by the blockage. Iterative calculations of the mass
balance equation for values of flow from the Tensleep/Amsden and the Madison indicate
that in 1983 the relative contribution of the 85 gpm artesian flow may have been
approximately 67 gpm from the Madison Limestone and 18 gpm from the
Tensleep/Amsden.

From these analyses, the following observations can be made regarding downhole
conditions, artesian flow, and water quality at Greybull #1:

• Artesian flow from the Madison Limestone is approximately 67 gpm;
• Low artesian flow rates under a wellhead pressure of 205 psi indicates
  very poor hydraulic conductivity (permeability) in the Madison
  Limestone. The permeability of the Madison Limestone at Greybull #1 is
  significantly less than at the Shell #1 and Shell #3 wells;
• Major ion water chemistry and TDS concentration from the Madison
  Limestone at Greybull #1 are likely to be similar to local wells and springs
  in the Madison Limestone; and the
• Contribution of poor quality water from the Amsden and Tensleep
  formations are responsible for the unusually high TDS concentration of
  artesian flow from the well.

2.3 Discussion of Greybull #1 Well Options

Three options are presented regarding the future use of Greybull #1:

1) Recomplete the well to improve the artesian flow rate and water
   quality;
2) Transfer well ownership; or
3) Plug and abandon the well.
2.3.1 Well Recompletion

The first and most difficult task of well recompletion requires that a 7-inch O.D. liner casing be hung from the 9 5/8 inch O.D. casing and set in the upper part of the Madison Limestone. The task is difficult due to small tolerances and casing/cement installation problems that may occur due to the demonstrated instability of the Amsden Formation. The liner casing would be cemented across approximately 50 feet of the uppermost Madison, all of the Amsden and Tensleep formations, and a portion of the existing 9 5/8-inch casing. The liner casing would seal off the Amsden and Tensleep formations to prevent further borehole caving and intrusion of poor quality water.

With the hole stabilized and the Amsden and Tensleep sealed off, there are a variety of approaches that could be used to obtain additional production. The approach used would depend on field conditions, the success/failure of initial efforts, and funding. Two general approaches will be described, but the discussion is not meant to be an exhaustive treatment of well recompletion options and procedures.

One approach is to clean-out and develop the open hole to the existing drilled depth of 3,238 feet and then perform an acid frac stimulation of the Madison Limestone. The objective of the acid frac is to open up and extend existing fractures in the limestone to increase artesian flow. An acid frac works best when there are suitable pre-existing fractures to open and extend. At Greybull #1, fracture development appears to be poor as indicated by the low artesian flow at high pressures. An acid frac will oftentimes increase short-term artesian flow by a factor of 2 to 4 times, but the long-term production is more difficult to predict. Assuming this degree of production enhancement, the resulting artesian flow from the Madison Limestone may be similar to artesian flows from the Shell #1 and Shell #3 wells (e.g., 110 to 180 gpm). Limiting well recompletion and stimulation efforts to only the Madison Limestone reduces the risk and expense associated with trying to drill and complete the well into the underlying Bighorn Dolomite. A cost estimate for this approach is $284,000 (Appendix A).

A second approach is to drill a 6 ¾-inch open hole through the remaining 50 to 100 feet of the Madison Limestone and an additional 600 feet to fully penetrate the underlying Jefferson and Bighorn Dolomite formations. The objective would be to
obtain additional production from the Bighorn Dolomite. If adequate artesian flow is not encountered in the Bighorn Dolomite, acid frac stimulation of the entire Madison Limestone/Jefferson/Bighorn Dolomite section could be performed.

A condition that needs to be recognized with any drilling and well stimulation efforts in the Bighorn Dolomite is the chance that the interbedded shales of the Jefferson Formation may collapse/bridge in a manner similar to what occurred at Shell #3, as will be discussed in Chapter 3. Casing and cementing off the Jefferson Formation to prevent a future collapse/bridge and subsequent loss of flow from the Bighorn Dolomite would require further reduction of casing and borehole diameter which is not practical. A cost estimate for this approach, excluding costs to case/cement off the Jefferson Formation, is approximately $349,000 (Appendix A).

From a hydrogeologic standpoint, the Greybull #1 well is not favorably located. The well is located near the axis of a gentle regional syncline (Plate 8-3, Chapter 8) which is a structural feature that hydrogeologists avoid when locating water wells. Conventional wisdom is to drill water wells on the crest of anticlines to increase the chance of encountering secondary permeability from extensional fractures. There is no structural reason, other than lineaments (Plate 8-2, Chapter 8), to expect enhanced permeability and large artesian flow in either the Madison Limestone or the Bighorn Dolomite at Greybull #1. At Greybull #1 it has been demonstrated that the Madison Limestone has very poor permeability and chances are the permeability of the Bighorn Dolomite will be similar.

In summary, the recompletion of Greybull #1 will be an expensive and risky endeavor whose success will depend on maintaining stability of the Jefferson Formation, a fortuitous encounter with adequate fracture permeability in the Bighorn Dolomite, and/or an acid frac stimulation procedure that connects the wellbore to nearby well-connected and high permeability fracture networks in the Madison Limestone and the Bighorn Dolomite.

2.3.2 Transfer Well Ownership

If the recompletion of Greybull #1 is not feasible or future recompletion efforts are unsatisfactory, the Town can transfer ownership of the well to someone that can put
water from the well to beneficial use. Perhaps the Whaley Cemetery, which owns the
land surrounding the well, would be interested in obtaining the well to help irrigate the
cemetery. This option would eliminate the expense to the Town of having to plug and
abandon the well.

2.3.3 Plug and Abandon Greybull #1 Well

If the Town decides that recompletion of Greybull #1 is not feasible and well
ownership can not be transferred, the Town will need to properly plug and abandon the
well. The Greybull #1 well is permitted for municipal and miscellaneous use.
Consequently, the Wyoming Department of Environmental Quality/Water Quality
Division (WDEQ) is the lead agency to approve the well plugging and abandonment
plan. The State Engineer’s Office (SEO) will also want to approve the plan, but will
probably concur with whatever the WDEQ believes is adequate.

Compliance with Chapter 11, Section 70, of WDEQ rules and regulations dealing
with the plugging and abandonment of municipal wells will require grouting the entire
open interval of the drilled well. The blockage would have to be drilled out and the hole
cleaned to total drilled depth. This will be very expensive and it can be presented to the
WDEQ as unnecessary. It is proposed to spot 300 feet of cement on top of the blockage
to kill the artesian flow, seal the upper Amsden Formation and all of the Tensleep
Formation, and get about 170 feet of cement up into the bottom of the casing (Figure 2-2).
After the cement sets, tag the top of the cement to verify plug placement. Fill the
remainder of the casing with ¾-inch chip bentonite from about 2,260 feet to the surface.
Cut off and mark the top of casing as required in the regulations.

This proposed plan, however, deviates from the WDEQ well plugging guideline.
As such, the proposed plugging plan and rational for the requested deviation must be
presented to the Lander WDEQ field office for review. If approved, then the SEO will
also need to approve the plugging plan.

A final plugging and abandonment plan and cost estimate will depend on the plan
approved by the WDEQ and the SEO. A preliminary estimate to plug and abandon
Greybull #1 as shown on Figure 2-2 is estimated to be $50,000 to $70,000 (Appendix A).
In the event that the Town transfers well ownership or decides to plug and abandon the well, the Town will have to transfer title of the 0.5 acre that surrounds the well, road access, and a 25 foot easement to the Town’s transmission line back to the Whaley Cemetery Association. This requirement complies with an agreement (Appendix A) between the Whaley Cemetery Association and the Town of Greybull.

2.4 **Recommendations for Greybull #1 Well**

Recompletion efforts at Greybull #1 are not warranted for the following reasons:

- large cost and high risk;
- demonstrated poor permeability characteristics of the Madison Limestone; and
- the well is not located on a major geologic structure conducive to enhanced permeability.

The amount of additional water that may be obtained by recompleting Greybull #1 can not be predicted with certainty. However, as will be discussed in subsequent chapters, there are demonstrated water supply increases available by installing pumping systems in the Shell #3 and Shell #1 wells and participation in the Big Horn Regional Water System. In the future, if the Town continues to experience water supply deficits, the Town would be better served to drill a new well at a location(s) with more favorable geologic structure and closer to town as discussed in the well siting study presented in Chapter 8.

Regarding the future use of Greybull #1, Wyoming Groundwater recommends that the Town attempt to find someone willing to assume well ownership under existing conditions. If this effort is unsuccessful, the Town is advised to plug and abandon the well.
TABLES AND FIGURES
### Table 2-1: Water Quality Data from the Greybull #1 Well. Greybull Wells Rehabilitation, Level II, Study

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<tr>
<th>Parameter, mg/L</th>
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<td>Bicarbonate</td>
<td>Tensleep, Amsden, Madison Lm.</td>
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<td>pH, s.u.</td>
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<td>Conductivity, umhos/cm</td>
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<tr>
<td>Total Dissolved Solids</td>
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FEBRUARY 1983 CONDITIONS
(Big Horn Engineering, 1983)

2. Shut-in pressure = 205 psi.
3. Open hole from 2,428 to 3,238 feet in Tensleep/Amsden/Madison Limestone Formations.
4. Cement Bond Log indicates no cement behind casing from 0 to 378 feet.

AUGUST 2, 2004 CONDITIONS

1. Artesian Flow = 10 gpm.
2. Shut-in pressure = 186 psi.
3. Bridge/Sloough at 2,560'.
4. Open hole from 2,428 to 2,560 feet Tensleep and Amsden (partial).

NOT TO SCALE

FIGURE 2-1
Existing Condition of Greybull #1
Greybull Wells Rehabilitation, Level II, Study
WYOMING GROUNDWATER, LLC
GREYBULL #1

WELL ABANDONMENT IDENTIFICATION ON CASING

18" SURFACE CASING
0-130'

CEMENT

12 1/4" DRILLED HOLE

9 5/8" CASING
0-2,428'

3/4-INCH CHIP BENTONITE
+2' TO 2,260'

CEMENT PLUG
2,260' TO 2,560'

BRIDGE/SLOUGH AT 2,560'
(AUGUST 2, 2004)

ORIGINAL 8 3/4"
DRILLED OPEN HOLE:
2,428' TO 3,238'

=2,260'

2,408'

378'

=2,260'

2,408'

TENSLEEP SANDSTONE
2,531'

AMSDEN FM.
2,688'

MADISON LIMESTONE

TD = 3,238'

ALL DEPTHS RELATIVE TO GROUND.

NOT TO SCALE

FIGURE 2-2
Proposed Design for Plugging and Abandonment of Greybull #1
Greybull Wells Rehabilitation, Level II, Study

WYOMING GROUNDWATER, LLC
CHAPTER 3
SHELL #3 WELL

3.1 Shell #3 Well Construction and History

The Shell #3 well was drilled in 1996 and put on-line in October 2000 to supplement water supplies from the Shell #1 and Shell #2 (aka Trapper) wells. Shell #3 was completed to a total depth of 2,061 feet and consists of an open hole completion in the Madison Limestone, Jefferson Formation, and Bighorn Dolomite as shown in Figure 3-1. The primary issue regarding Shell #3 has been a decline in artesian flow from 220 gpm to approximately 112 gpm. For seven months prior to March 2005, artesian flow had been steady at 112 to 115 gpm with 12 psi pressure at the wellhead. Detailed information regarding the construction, testing, and evaluation of Shell #3 is provided in Nelson Engineering (1997), Lidstone (2002), and Engineering Associates (2003b). Appendix B in Volume II contains documents and information regarding Shell #3 that support the discussion provided in this chapter.

When Shell #3 was completed in September 1996, the artesian flow rate was approximately 65 gpm (Nelson Engineering, 1997). In April 1997, the well was acid-fraced to enhance aquifer permeability. Prior to the acid-frac, the well flowed 59 gpm without back pressure and had a shut-in pressure of 101.5 psi. Post acid-frac flow testing indicated a sustained flow of 215 gpm for 8 days at 15 psi and a pre-test shut-in pressure of approximately 68 psi. Pre-frac and post-frac specific capacity values for the well were 0.26 gpm/foot of drawdown and 1.8 gpm/foot, respectively. Table 3-1 summarizes pre-frac and post-frac flows and pressures reported by Lidstone (2002). The acid-frac resulted in a substantial initial increase in artesian flow and an unusual reduction in head that is reflected in the lower pressure at the wellhead.

Throughout 2001 and early 2002, artesian flow from Shell #3 declined from 201 gpm to 122 gpm (Lidstone, 2002). In an effort to determine the cause for the decline in flow, Lidstone and Associates was hired to evaluate the well. Step tests indicated that the sustainable yield of the well was on the order of 110 gpm. A downhole video performed on May 1, 2002, revealed a blockage at 1,545 feet caused by the collapse of sidewall material from the middle/lower portion of the Jefferson Formation. It was not known
whether sidewall material had bridged across the open hole at 1,545 feet or had completely filled the borehole from 1,545 to 2,061 feet. Lidstone (2002) attributed the decline of artesian flow and pressure to the collapse of the borehole and subsequent loss of artesian flow and pressure from the Bighorn Dolomite and the deposition of calcite and dolomite along fracture surfaces.

As part of an analysis of water supply enhancement options for the Town of Greybull, Wester-Wetstein (in Engineering Associates, 2003b) provided additional evaluation of the potential cause(s) for the decline of artesian flow and pressure at Shell #3. The Wester-Wetstein evaluation provides alternative explanations for the decline of artesian flow and pressure. Technical evaluations by Wester-Wetstein and Wyoming Groundwater are provided in Appendix B.

3.2 Shell #3 Well Rehabilitation

The objective of Shell #3 rehabilitation was to remove the downhole blockage, determine the likely cause for flow and pressure decline, and attempt to increase artesian flow using methods that would not compromise the future use of the well. The wellhouse could not be removed or demolished, so all work was performed in the limited space within a walled-off corner of the wellhouse and through the well access hatch on the roof.

Weston Engineering, Inc. of Upton, Wyoming, was subcontracted by Wyoming Groundwater to provide contractor services for well rehabilitation. A service rig (#111, Conncticut-Emsco 375-D) equipped with a power swivel was elevated adjacent to the wellhouse. Well rehabilitation activities began on March 16 and were concluded on March 29, 2005. The well rehabilitation tasks that follow are presented in the order of completion.

3.2.1 Permits and Access Agreements

Well evaluation and rehabilitation activities did not require permits from the State Engineer’s Office or the Wyoming Department of Environmental Quality/Water Quality Division (WDEQ). The SEO and WDEQ were contacted and provided a verbal description of the proposed work. Both agencies have been notified regarding the results of well rehabilitation activities.
Authorization from WDEQ was obtained for the temporary discharge of water to the ground surface and Shell Creek associated with the flow/pump testing and disinfection of the well. Work was performed in compliance with monitoring and reporting requirements of authorization #WYG720084.

The Shell #3 wellhouse is located on land owned by Mr. Chuck Landers. Verbal agreement was obtained to remove fencing, discharge water, and to restore the site to pre-work conditions to his satisfaction.

3.2.2 Pre-Rehabilitation Artesian Flow Test

Prior to well rehabilitation, a constant drawdown flow test was conducted at Shell #3 on March 9, 2005. The purpose of the flow test was to document well production and aquifer transmissivity prior to attempts to enhance production. Prior to the test, the well had been shut-in for 44.5 hours and the shut-in pressure was 59.3 psi. The constant drawdown (pressure) test consisted of adjusting the well valve to maintain a constant pressure of 12 psi at the wellhead while recording the change in artesian flow rate with time. Flow rate values were measured by the inline flow meter and read off the digital readout in the wellhouse. Appendix B contains test data plots.

Table 3-2 summarizes calculated values of aquifer transmissivity for discharge/recovery data and specific capacity (Figures B-1 and B-2, Appendix B). After 4.3 hours, the artesian flow declined from an initial value of 220 gpm to a final value of 131 gpm. The average flow rate during the test was 138 gpm. The calculated pre-rehabilitation aquifer transmissivity value is approximately 2,600 gallons per day per foot (gpd/ft). This value is slightly less than the post-frac transmissivity value of 3,231 gpd/ft calculated from a similar constant drawdown (pressure) test conducted in April 1997 (Nelson Engineering, 1997).

In early 2005, prior to any well testing or rehabilitation, Shell #3 was operated continuously with a typical flow of 112 gpm with 12 psi at the wellhead (as observed by Wyoming Groundwater on February 4, 2005). On March 16, 2005, prior to well rehabilitation activities, the well shut-in pressure was 62.8 psi.
3.2.3  **Casing Integrity Test**

Evaluation of Shell #3 began with a casing integrity test designed to determine if there were any compromises in the steel casing that would allow water from the well to leak into lower head formations above the Madison Limestone. On March 17, 2005, an inflatable packer was installed in the casing at 1,019 to 1,023 feet. Prior to packer inflation, a transducer and data logger were used to monitor water level changes in the well. Assuming that the packer was sealed inside the casing, a water level decline or continued flow would indicate a compromise in the casing above the packer. Artesian flow ceased when the packer was fully inflated. The packer remained inflated for 2 hours and systematic water level declines or artesian flow was not observed (Figure B-3, Appendix B).

The results of the packer test confirmed that there were no compromises in the casing that could explain the low head or the decline in shut-in pressure after the acid-frac.

3.2.4  **Well Clean-Out**

On March 21-22, 2005, Weston Engineering, Inc. attempted to drill through the blockage and clean-out the open hole using a service rig equipped with a power swivel and 7 7/8-inch tricone bit. Chlorinated water from the adjacent 100,000 gallon storage tank was used as drilling fluid to remove cuttings. To prevent contamination of the well, drilling mud and additives were not used.

On March 21, the top of blockage was tagged at 1,545 feet and approximately 34 feet of material was drilled through to 1,579 feet. Drilling through the first 12 feet of material to 1,567 feet was slow and rough; however, the next 22 feet of drilling was more smooth and rapid.

On March 22, approximately 28 feet of the hole had filled back in to 1,551 feet. Very difficult drilling was encountered from 1,553 to 1,556 and cuttings/sidewall material were falling in above the bit and preventing bit rotation. Eventually, the bit got stuck in the hole for approximately 15 minutes. The bit was worked free, but further drilling efforts were suspended when the source of drilling water was consumed and borehole conditions appeared too unstable.
A phone conference was held between project representatives of the Town, WWDC, Wyoming Groundwater, and Weston Engineering to discuss well clean-out options. The hole was very unstable in the Jefferson Formation and additional efforts to clean out the well would require the use of drilling mud to stabilize the hole. Drilling mud was not a viable option, so the decision was made to focus further rehabilitation efforts on the Madison Limestone.

The inability to remove the blockage and open up the Bighorn Dolomite prevented an unequivocal evaluation of the production and pressure contributions to the well from the Bighorn Dolomite. However, technical comments provided by Wester-Wetstein (Engineering Associates, 2003b) and Wyoming Groundwater in Appendix B provide the basis for an opinion that the Bighorn Dolomite probably does not contribute a significant amount of artesian flow and that the pressure decline observed after the acid-frac was not a result of the blockage. A qualitative observation that supports this opinion is that increased artesian flow from Shell #3 was not observed while drilling in the Bighorn Dolomite (Nelson Engineering, 1997).

3.2.5 Geophysical Logging

A unique aspect of Shell #3 is that the casing was set 245 feet into the upper part of the Madison Limestone (Figure 3-1). A production enhancement option was to perforate the casing adjacent to the Madison Limestone (i.e., 810 to 1,055 feet). On March 28, 2005, Goodwell Inc. performed geophysical logs consisting of caliper, gamma ray, and neutron. These logs were run from 10 to 1,460 feet to identify water bearing zones in the Madison Limestone that may be suitable for shot perforation. Geophysical logs are presented in Appendix B.

The neutron log was used to identify water bearing zones and the gamma log was used to identify lithology changes in the cased portion of the Madison Limestone. Table 3-3 summarizes interval characteristics in the Madison Limestone deduced from the geophysical logs. Based primarily on the neutron log, the cased interval from 1,000 to 1,054 feet (a 54 foot interval immediately above the bottom of the casing) appeared to have relatively good water filled porosity; whereas the remaining Madison Limestone from 810 to 1,000 feet appeared to have relatively poor porosity, shale, or infilled karst.
3.2.6 **Shot Perforation**

On March 28, 2005, Goodwell Inc. shot perforated the casing from 1,002 to 1,045 feet. Perforations consisted of 90 gram frac-jet shots spaced every 6 inches (2 shots/foot, 87 shots total). The effect of shot perforation on artesian flow is inconclusive as indicated by the data presented in Table 3-4. Prior to shot perforation, the well had been shut-in for almost 6 days and the artesian flow was 173 gpm after opening the well to perform geophysical logging and shot perforating. Twenty-four hours after shot perforation, the artesian flow was 173 gpm. Consequently, it is difficult to ascertain whether the flow increase from 149 to 173 gpm was due to the shot perforation or from aquifer recovery associated with the 6 days of shut-in.

3.2.7 **Downhole Camera Survey**

On April 5, 2005, Weston Engineering, Inc. performed a downhole camera survey at Shell #3 immediately after a failed pump test (see Section 3.3.2). The camera had downview and sideview capabilities that allow a detailed inspection of the sidewall. During the survey, the well was allowed to flow (171 gpm) and a piece of flagging was attached to the light support to ascertain changes in up or side hole flow. Appendix B contains a detailed log of downhole features and conditions observed during the camera survey. The Town and WWDC were provided VHS and DVD copies of the camera survey.

Casing and joints appear to be in good condition. Much of the calcite scale that was present on the casing in the May 1, 2002, well video was removed during well rehabilitation and pump test activities. Shot perforations appear to be approximately 1-inch diameter and many of the holes are partially filled with scale chips which may indicate not much flow out of the perforations. In the video, perforations were observed from approximately 999.4 to 1,041.8 feet.

The open interval from 1,053 to 1,147 feet in the upper third/half of the Madison Limestone appears to be the most permeable interval based on the presence of open voids (karst), fractures, and clear water in the borehole. Aggressive flow from a horizontal fracture at 1,147 feet suggests that a large portion of the flow from Shell #3 is from this

3-6
fracture. Silt/clay suspended in the water that discharges from this fracture indicates that the fracture is still developing. Water in the wellbore is clear above 1,147 feet whereas wellbore water is cloudy from 1,147 to the total surveyed depth of 1,536 feet. More massive/thickly bedded limestone, cloudy water, and the observed very slow upward flow of silty water below 1,147 feet suggests that relatively minor flow is derived from the Madison Limestone below this depth.

The thinly bedded grey shale in the lower Jefferson Formation is very unstable and the sidewall has collapsed across an estimated 32 feet of borehole. Small sidewall wash-outs were observed from 1,498 to 1,530 feet. A large void was observed from 1,535 to 1,537 feet. The camera was not advanced to the bottom of the hole due to unstable and potentially dangerous conditions in the void. Subsequent well disinfection activities on April 19, 2005, determined that the total depth of the well is approximately 1,545 feet. Review of the May 1, 2002, camera survey by Lidstone (2002) indicates that the void observed on April 5, 2005, from 1,535 to 1,537 feet was created during well clean-up, rehabilitation, and pump test activities (this study). The area of sidewall collapse (i.e., void) observed at 1,535 feet is 10 to 20 feet above the section of very difficult drilling (see Section 3.2.4) and it is likely that the area of collapsed/unstable sidewall extends to 1,567 feet.

3.3 Results of Pump Tests at Shell #3

From March 31 to April 13, 2005, Wyoming Groundwater and Weston Engineering, Inc. conducted pump tests at Shell #3. Weston Engineering Inc. provided contractor services related to wellhead modifications, installation/removal of a temporary pump, power, water conveyance, and well disinfection. Wyoming Groundwater was responsible for test design, pre-test monitoring, hydrologic/water quality monitoring, and data analysis during the test.

The objective of testing was to define well/aquifer performance under pumping conditions for subsequent evaluation of the feasibility of obtaining additional water supply from a pumping system in Shell #3. All data are from the pumping well, Shell #3, because there were not any nearby wells available for use as observation wells. The project notebook contains pump data from Shell #3.
Water levels in Shell #3 were measured and recorded using a 250 psi transducer set above the pump and a Hermit 1000 C Data Logger. An air line was installed downhole with the transducer to verify transducer values and provide a back-up in case of transducer or data logger failure. During all tests, the transducer and data logger provided accurate data as verified by air line values, field calibration, and set depth calculations. Pump rates were measured using a manometer on a 4 x 6 inch orifice pipe. An on-site generator provided power to an 8-inch diameter 75 horsepower 7-stage submersible pump. The wellhead was disconnected from the piping to the storage tank, and water from the tests was conveyed by hose to an ephemeral drainage that discharges into Shell Creek.

After the completion of well testing activities, the well was disinfected on April 19 by running a bailer filled with 12 pounds of hypochlorite tablets (65% available chlorine) up and down the open hole interval until all tablets were dissolved. The well was shut-in for 3 days and subsequent total coliform and E-Coli tests were negative (absent) for these biological indicators (Appendix B).

3.3.1 Shell #3 Step Test

On March 31, 2005, a step-test was conducted using three steps of 100 minute duration at pump rates of 250, 325, and 400 gpm. From the step-test data it was determined that 400 gpm was an appropriate pump rate for a 7-day test.

3.3.2 Shell #3 Pump Test at 400 gpm

On April 1, 2005, a constant rate discharge pump test was started at a pump rate of 400 gpm. On April 3, after 46.5 hours of pumping, the pump failed (motor thrust bearings) and the test was terminated. Data from this test are not presented in this report. However, the test indicated that a 7-day test could be conducted at 450 gpm.

3.3.3 Shell #3 Pump Test at 450 gpm

On April 6, 2005, a constant rate discharge pump test was started at a pump rate of 450 gpm and maintained continuously for 168 hours (7 days). There were no
interruptions or significant variations in pump rate. The pump was set at approximately 500 feet.

The test was started under flowing artesian conditions (164 gpm) rather than under ideal conditions of the well being shut-in. Under shut-in conditions, the transducer would have been overpressured and sealing the well properly was very difficult. Regardless, the non-ideal starting conditions did not likely affect the magnitude or long-term trend of drawdown. Estimates of total drawdown and specific capacity include the drawdown associated with an assumed maximum shut-in pressure of 62.8 psi (Table 3-4).

Figure 3-2 shows the time-drawdown data from Shell #3 while being pumped at 450 gpm for 7 days. Drawdown values are relative to the wellhead and because the test was started under flowing conditions, these values also represent the depth to water in the well. After 7 days of continuous pumping at 450 gpm, the depth to water was approximately 308 feet. However, the total head decline caused by pumping was 453 feet (i.e., 308’ + 145’ shut-in pressure). The calculated specific capacity of the well is 1.0 gpm per foot of drawdown (i.e., 450 gpm/453 ft. of drawdown).

Multiple straight lines can be drawn through the drawdown data because the time-drawdown slope continued to decrease as the test progressed. For example, the early-time data from 1 to 10 minutes has a slope of 118 ft/log cycle whereas the late-time data from 7,000 to 10,000 minutes has a slope of 21 ft/log cycle. The decreasing slope with time indicates that the Madison Limestone is heterogeneous and that areas of increasing permeability are encountered as the cone of depression expands from the well. An alternative interpretation is that the well was developing itself as the test progressed. Considering the silt that was observed to discharge from the horizontal fracture at 1,147 feet under flowing artesian conditions, it is not unreasonable to suspect that this fracture was being developed during the pump test. Water discharged during the test was clear with a laboratory measured turbidity of 1.1 ntu at the end of the test (Table 3-5).

Regardless, the rate of drawdown declines noticeably during pumping which is a positive condition for extended pumping.

The calculation of aquifer transmissivity has limited value given the heterogeneous and fractured condition of the Madison Limestone which violates the assumptions of typical aquifer analysis. Using the Cooper-Jacob straight line method,
calculated transmissivity values from the drawdown data vary from 1,000 gpd/ft (early-time data) to 5,700 gpd/ft (late-time data) depending on what portion of the time-drawdown data is selected for analysis.

Recovery data was collected immediately after pump test termination on April 13, 2005. However, a wellhead seal blew at 11:00 pm as pressure built up inside the casing, so only 9 hours of recovery data were collected. Figure 3-3 shows recovery data and calculated transmissivity values for two straight-line segments of the recovery curve.

In summary, the constant rate pump test demonstrated that Shell #3 can be pumped at a rate of 450 gpm with a depth to water on the order of 310 feet. Negative boundary conditions that cause accelerated drawdown were not encountered; in fact, the semi-log rate of drawdown continues to decrease with time due to positive boundaries and/or continued well development during the test.

3.3.4 Water Quality

On April 13, 2005, at the end of the 450 gpm pump test, a water sample was collected and analyzed by Energy Laboratory in Casper, Wyoming. Table 3-5 lists the results of the analysis. There were not any noticeable changes in major cation/anion water chemistry between the pre-test and end of pump test samples. The water quality satisfies EPA standards for drinking water. The only objectionable characteristic is that the water is very hard (i.e., > 180 mg/L as CaCO₃).

As observed in the May 1, 2002, downhole camera survey, calcium carbonate scale had precipitated on the inside of the casing. A geochemical speciation model, Geochemist’s Workbench®, was used to assess the potential for the precipitation of minerals from Shell #3 water. The speciation modeling reveals that water from Shell #3 is slightly super-saturated with respect to quartz and calcite (Appendix B). If allowed to equilibrate, small amounts of silica and calcite would precipitate in the well, and larger amounts of calcite would precipitate in the storage tank after the water equilibrates with the atmosphere.
3.4 Post-Rehabilitation Artesian Flow Test and Observations

On May 11, 2005, after well rehabilitation and testing was completed, a constant drawdown (pressure) flow test was conducted at Shell #3. The purpose of the flow test was to compare post-rehabilitation well performance with the pre-rehabilitation flow test conducted on March 9, 2005 (see Section 3.2.2). Prior to the test, the well had been shut-in for 16 hours and the shut-in pressure was 60.0 psi. The constant drawdown (pressure) test consisted of adjusting the well valve to maintain a constant pressure of 12 psi at the wellhead while recording the change in artesian flow rate with time. Flow rate values were measured by the existing inline flow meter and read off the digital readout in the wellhouse. Test conditions for this test were nearly identical to conditions during the pre-rehabilitation flow test. Appendix B contains test data plots.

Table 3-2 summarizes calculated values of aquifer transmissivity for discharge/recovery data and specific capacity (Figures B-4 and B-5, Appendix B). After 4.2 hours, the artesian flow declined from an initial value of 311 gpm to a final value of 196 gpm. The average flow rate during the test was 206 gpm. The calculated post-rehabilitation transmissivity value is 3,900 gpd/ft which is an increase of approximately 50% over the calculated transmissivity value for the pre-rehabilitation flow test. Specific capacity value for the 4 hour test also increased by 50%.

Pre- and post-rehabilitation flow tests at Shell #3 suggest that the artesian flow may have increased by approximately 65 gpm (i.e., 196 – 131 gpm). However, subsequent continuous artesian production (i.e., Shell #3 not shut-in) from October 2005 to October 2006 has ranged from 125 to 150 gpm at 11 psi (Ron Vanderpool, pers. comm., Oct. 2006). Well production during 2006 indicates a long-term steady state improvement on the order of 25 gpm as a result of rehabilitation efforts at Shell #3.

3.5 Summary of Shell #3 Rehabilitation and Testing

As a result of well rehabilitation and testing, artesian flow from Shell #3 under typical operating conditions has been increased by about 25 gpm. The anticipated rate of artesian flow to the storage tank should range from 125 to 150 gpm. Well rehabilitation activities consisted of shot perforating the lower 43 feet of casing and well development via the pump test and attempts to drill out the blockage. Existing data can not determine
which of these three activities were primarily responsible for the increase in flow. Based
on the well video and flow monitoring, development of fractures during well clean-out
may have been important.

Well rehabilitation efforts were unsuccessful with respect to cleaning out the hole
and regaining lost production from the Bighorn Dolomite. It is Wyoming Groundwater’s
opinion that the Bighorn Dolomite will not provide sufficient additional flow to warrant
the cost and risks associated with future attempts to remove the blockage at 1,545 feet.
Present day transmissivity and specific capacity values are similar to values calculated
immediately after the acid-frac in April 1997 (Table 3-4). The well video clearly
illustrates unstable sidewall conditions in the Jefferson Formation.

As discussed in technical memorandums in Appendix B, the decline in pressure
after the acid-frac in April 1997 was probably caused by connecting with an even lower
pressure zone in the already underpressured Madison Limestone. The blockage of the
Bighorn Dolomite is unlikely to have had any affect on well pressure. Unfortunately, this
could not be proven by direct evidence that would have been provided if the blockage
had been removed.

The pump test at Shell #3 demonstrates that the well can be pumped at 450 gpm
for extended time periods and that installation of a pumping system can provide an
additional 300 gpm from present day artesian production.
TABLES AND FIGURES
<table>
<thead>
<tr>
<th>Date</th>
<th>Artesian Flow gpm</th>
<th>Wellhead Pressure psi</th>
<th>Shut-in Pressure psi</th>
<th>Comments</th>
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<td>65</td>
<td>open</td>
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<td>Immediately after well completion</td>
</tr>
<tr>
<td>Apr-97</td>
<td>59</td>
<td>2</td>
<td>101.5</td>
<td>Pre-acid frac; 9 hour flow test</td>
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<td>Apr-97</td>
<td>215</td>
<td>12 - 15</td>
<td>68 - 70</td>
<td>Post-acid frac; 7 day flow test</td>
</tr>
</tbody>
</table>

Data Source: Lidstone (2002)
Table 3-2: Results of Shell #3 Pre-Rehabilitation and Post-Rehabilitation Constant Drawdown (Pressure) Flow Tests
Greybull Wells Rehabilitation, Level II, Study

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Test Date</th>
<th>Test Duration</th>
<th>End of Test Flow Rate gpm</th>
<th>Average Flow Rate gpm</th>
<th>Wellhead Pressure psi</th>
<th>Calculated Transmiss. Discharge gpd/ft</th>
<th>Calculated Transmiss. Recovery gpd/ft</th>
<th>Calculated Specific Capacity gpm/ft</th>
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<td>4.3</td>
<td>131</td>
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<td>169</td>
<td>59</td>
<td>215</td>
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<td>431</td>
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<td>Pre-acid frac</td>
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<td>Depth Interval feet bgs</td>
<td>Log Response</td>
<td>Madison Limestone Characteristic</td>
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<tr>
<td>810 to 870</td>
<td>Neutron trace to right (high) Gamma kicks to right (high)</td>
<td>Karst (dirty limestone), poor porosity</td>
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<td>870 to 958</td>
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<td>Limestone; poor porosity</td>
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<td>958 to 990</td>
<td>Neutron trace kicks left (low) Gamma trace kicks right</td>
<td>Shale interbed; high porosity but probable low permeability</td>
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<td>Neutron trace kicks right Gamma trace to left Bulk density trace far right</td>
<td>Limestone; poor porosity</td>
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<td>1,000 to 1,054</td>
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<td>Limestone; higher relative porosity</td>
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<td>1,060 to 1,152</td>
<td>Variable neutron with kicks to left Gamma trace to left Highly variable bulk density Caliper log indicates ratty hole</td>
<td>Limestone; high relative porosity at: 1058, 1066, 1105, 1128, and 1140 to 1148</td>
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<td>1,152 to 1,420</td>
<td>Variable neutron mostly to right Gamma trace to left Bulk density to right w/ left kick at 1,300 Caliper log consistent w/ right kick at 1,280 to 1,300</td>
<td>Limestone; intermediate porosity; possible high porosity zone at 1,280 to 1,300</td>
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</tbody>
</table>
Table 3-4: Artesian Flow and Wellhead Pressure Measurements at Shell #3 During Field Work
Greybull Wells Rehabilitation, Level II, Study

<table>
<thead>
<tr>
<th>Date</th>
<th>Time to Fill 34 gal container sec.</th>
<th>Artesian Flow gpm</th>
<th>Pressure at Wellhead psi</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>03/07/05</td>
<td>Flow meter</td>
<td>112</td>
<td>10</td>
<td>Artesian flow to storage tank</td>
</tr>
<tr>
<td>03/16/05</td>
<td></td>
<td></td>
<td>62.8</td>
<td>Shut-in for 9 days</td>
</tr>
<tr>
<td>03/18/05</td>
<td>13.7</td>
<td>149</td>
<td>0</td>
<td>Pre-clean out</td>
</tr>
<tr>
<td>03/21/05</td>
<td>14.1</td>
<td>145</td>
<td>0</td>
<td>Pre-clean out</td>
</tr>
<tr>
<td>03/22/05</td>
<td>14.0</td>
<td>146</td>
<td>0</td>
<td>During clean out</td>
</tr>
<tr>
<td>03/28/05</td>
<td>11.8</td>
<td>173</td>
<td>60.7</td>
<td>Shut-in for 5.8 days; pre-shot perforation - 2 hours</td>
</tr>
<tr>
<td>03/29/05</td>
<td>11.8</td>
<td>173</td>
<td>0</td>
<td>24 hrs after shot perforation</td>
</tr>
<tr>
<td>03/30/05</td>
<td>11.4</td>
<td>179</td>
<td>0</td>
<td>Pre-step test; pump in well (PIW)</td>
</tr>
<tr>
<td>03/31/05</td>
<td>11.8</td>
<td>173</td>
<td>0</td>
<td>Pre-step test; PIW</td>
</tr>
<tr>
<td>04/01/05</td>
<td>11.6</td>
<td>176</td>
<td>0</td>
<td>Pre-400 gpm test; PIW</td>
</tr>
<tr>
<td>04/04/05</td>
<td>11.7</td>
<td>174</td>
<td>0</td>
<td>24 hrs after 400 gpm test; PIW</td>
</tr>
<tr>
<td>04/05/05</td>
<td>11.9</td>
<td>171</td>
<td>0</td>
<td>56 hrs after 400 gpm test; pump out of well (POW)</td>
</tr>
<tr>
<td>04/06/05</td>
<td>11.9</td>
<td>171</td>
<td>0</td>
<td>72 hrs after 400 gpm test; POW</td>
</tr>
<tr>
<td>04/06/05</td>
<td>12.4</td>
<td>165</td>
<td>0</td>
<td>75 hrs after 400 gpm test; PIW</td>
</tr>
<tr>
<td>04/14/05</td>
<td>13.0</td>
<td>157</td>
<td>0</td>
<td>24 hours after 450 gpm test; PIW</td>
</tr>
<tr>
<td>04/18/05</td>
<td>11.8</td>
<td>173</td>
<td>0</td>
<td>120 hours after 450 gpm test; PIW</td>
</tr>
<tr>
<td>04/18/05</td>
<td>11.4</td>
<td>179</td>
<td>0</td>
<td>124 hours after 450 gpm test; POW</td>
</tr>
<tr>
<td>07/19/05</td>
<td>Flow meter</td>
<td>165</td>
<td>9</td>
<td>Artesian flow to storage tank</td>
</tr>
<tr>
<td>Parameter, mg/L</td>
<td>Pre-Rehab and Testing Sample Date</td>
<td>End of Pump Test Sample Date</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------------------------</td>
<td>----------------------------------</td>
<td>------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbonate as CO₃</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bicarbonate as HCO₃</td>
<td>234</td>
<td>239</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium</td>
<td>51.3</td>
<td>48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chloride</td>
<td>3</td>
<td>&lt; 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fluoride</td>
<td>0.4</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magnesium</td>
<td>28.6</td>
<td>27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrate + Nitrite as N</td>
<td>0.4</td>
<td>0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potassium</td>
<td>1.2</td>
<td>1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium</td>
<td>2.7</td>
<td>2.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulfate</td>
<td>38</td>
<td>32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conductivity, umhos/cm</td>
<td>440</td>
<td>449</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH, s.u.</td>
<td>7.86</td>
<td>7.81</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field Temperature, °C/°F</td>
<td>14.8/59</td>
<td>15.6/60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Dissolved Solids, 180 °C</td>
<td>289</td>
<td>235</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Dissolved Solids, calc.</td>
<td>361</td>
<td>352</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hardness, as CaCO₃</td>
<td>246</td>
<td>231</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Suspended Solids</td>
<td>N.A.</td>
<td>3.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turbidity, NTU</td>
<td>N.A.</td>
<td>1.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gross Alpha, pCi/L</td>
<td>N.A.</td>
<td>4.1 +/- 1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gross Beta, pCi/L</td>
<td>N.A.</td>
<td>2.1 +/- 2.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radium 226, pCi/L</td>
<td>N.A.</td>
<td>&lt; 1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radium 228, pCi/L</td>
<td>N.A.</td>
<td>&lt; 1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radium 226 + 228, pCi/L</td>
<td>N.A.</td>
<td>&lt; 1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uranium, mg/L</td>
<td>N.A.</td>
<td>0.0021</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A/C balance, %</td>
<td>3.06</td>
<td>1.14</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
SHELL #3

14" SURFACE CASING 0'-150'

9 5/8" CASING (9.0" I.D.) 0'-1,056'

CEMENT

INTERVAL OF SHOT PERFORATIONS 1,002'-1,045'

8 3/4" OPEN HOLE 1,056'-1,548'

1,548'

BRIDGE AT 1,548' OR SLOUGH 1,548'-2,050'

POST TENSLEEP FORMATIONS 410'

TENSLEEP & AMSDEN FMS. 810'

MADISON LIMESTONE

JEFFERSON FM. 1,600'

BIGHORN DOLOMITE

GALLATIN FORMATION 2,020'

TD = 2,061'

ALL DEPTHS RELATIVE TO GROUND

FIGURE 3-1
Shell #3 Well Condition
April 2005
Greybull Wells Rehabilitation, Level II, Study

WYOMING GROUNDWATER, LLC
Figure 3-2: Shell #3 Time-Drawdown Data From 7-Day, 450 gpm, Pump Test at Shell #3
April 6 - 13, 2005, Greybull Wells Rehabilitation, Level II, Study

Governing Equation: \( T, \text{ gpd/ft} = \frac{264 (Q)}{\Delta s} \)
\( Q = 450 \text{ gpm} \)

\( T_1 = \frac{118,800}{118} = 1,000 \text{ gpd/ft} \)
\( T_2 = \frac{118,800}{48} = 2,500 \text{ gpd/ft} \)
\( T_3 = \frac{118,800}{29} = 4,100 \text{ gpd/ft} \)
\( T_4 = \frac{118,800}{21} = 5,600 \text{ gpd/ft} \)

Note: Add 145 ft (62.8 psi shut-in pressure) to drawdown values to get total head decline caused by pumping.
Figure 3-3: Shell #3 Recovery Data From 7-Day, 450 gpm, Pump Test at Shell #3
April 13, 2005, Greybull Wells Rehabilitation, Level II, Study

Governing Equation: $T, \text{ gpd/ft} = \frac{264 \times (Q)}{\Delta s}$

$Q = 450 \text{ gpm}$

$T_1 = \frac{118,800}{182} = 650 \text{ gpd/ft}$

$T_2 = \frac{118,800}{37} = 3,200 \text{ gpd/ft}$

Wellhead seal blew 9 hours into recovery, $t/t' = 20$

$\Delta s_1$ over 1 log cycle = 182 ft.

$\Delta s_2$ over 1 log cycle = 37 ft.
CHAPTER 4
SHELL #1 WELL

4.1 Background

In 1984-85, the Shell Valley #1 and Shell Valley #2 (aka Trapper wells) wells were completed as part of a WWDC funded Level II Feasibility Study. For brevity, the Shell Valley Wells will be referred to individually in this report as Shell #1 and Shell #2. The original intent of these wells was to augment irrigation supplies of the Shell Valley Watershed Improvement District. As a result of inadequate production for irrigation purposes, the District provided the use and ownership of the wells to the Town of Greybull for municipal water supply. A detailed description of well completion and testing is provided in Morrison-Maierle (1986) and a summary is provided in Nelson Engineering (1995).

As shown on Figure 1-1, Shell #1 and Shell #2 are located just east of the community of Shell in Sections 35 and 26 of T53N, R 91W. Since 1986, these two flowing artesian wells have provided the majority of municipal water to the Town of Greybull. Water from each well is commingled, chlorinated, and discharged into a 0.35 million gallon (MG) storage tank located near the wells. At present, the combined artesian production from these wells is approximately 1,140 gpm.

There are unique aspects to the construction and hydrogeology of the Shell #1 and Shell #2 wells that are important to recognize. Figure 4-1 illustrates well construction features and the following summarizes important points from well diagrams and previous studies.

- Shell #1 and Shell #2 are located only 567 feet from each other.
- Shell #1 is completed in the Madison Limestone. Shell #2 is completed in both the Madison Limestone and Bighorn Dolomite.
- Hydraulic connection between each well is provided by the Madison Limestone.
- Shell #1 presently provides approximately 180 gpm of artesian flow from the Madison Limestone.
• Shell #2 presently provides approximately 960 gpm of artesian flow from the Madison Limestone (27% of flow) and Bighorn Dolomite (73% of flow).

• Despite their proximity, distinctly different hydraulic properties were encountered in the Madison Limestone and Bighorn Dolomite at each well. For example, Shell #1 encountered groundwater production from the Madison Limestone but did not encounter water production in the Bighorn Dolomite. Shell #2 encountered large production in the Bighorn Dolomite and relatively less production in the Madison Limestone.

• Shell #1 was constructed with 598 feet of 14-inch casing in the upper part of the well; whereas Shell #2 was constructed with 1,813 feet of 9 5/8-inch casing in the upper part of the well.

• At Shell #2, the Madison Limestone is “recharged” by flow from the underlying Bighorn Dolomite. Testing by Morrison-Maierle (1986) showed that the head in the Bighorn Dolomite was approximately 20 psi greater than the head in the Madison Limestone.

During the course of this Level II study, it was apparent that pumping systems in the Greybull water supply wells may provide an economical option to obtain additional water supplies. Review of the Shell #1/Shell #2 system indicated that Shell #1 is better suited than Shell #2 for evaluation of a pumping system. This conclusion is based primarily on the fact that Shell #1 has a large diameter casing that can accommodate a pump and allow the option of both artesian flow and pumping. Shell #2 has a 9 5/8-in O.D. (8 ¾” I.D.) casing such that a 8 1/8-inch diameter pump capable of producing up to 1,200 gpm would have only 1/8 to ¼ inch of annular space between the pump and casing. This small tolerance would require a very straight well, be prone to blockage by calcite scale, and would seriously impede 960 gpm of artesian flow. Consequently, Shell #2 was not deemed a viable well for a pumping system.
4.2 Objectives and Approach

The Level II study objective at Shell #1 and Shell #2 was to conduct a pump test at Shell #1 to determine the pumping capacity of Shell #1, and the magnitude of hydraulic interference and subsequent reduction of artesian flow at Shell #2. Drawdown and pump rate data from Shell #1 and artesian flow data from Shell #2 were used to determine the amount of additional water that could be obtained from a pump system at Shell #1.

4.3 Permits and Access Agreements

Authorization from WDEQ/WQD was obtained for the temporary discharge of water to the High Line irrigation ditch associated with the pump testing and disinfection of Shell #1. Work was performed in compliance with monitoring and reporting requirements of authorization #WYG720087.

Permission was obtained from Mr. Kincaid Reed, operator of the High Line irrigation ditch, to discharge water from the pump test into the irrigation ditch.

Shell #1 is located on and surrounded by land owned by the Bureau of Land Management (BLM). A land use permit (WYW-162881) was obtained from the BLM that authorized the use of public land for the installation of surface piping that conveyed pump test discharge to the irrigation ditch. Work was performed in compliance with the land use permit.

4.4 Pre-Pump Test Conditions

On April 14, 2005, prior to the pump test at Shell #1, a 250 psi transducer and data logger were installed on the wellheads of Shell #1 and Shell #2 to record a normal operation cycle of these wells. In-line valves at each well open and close automatically in response to the water level in the 0.35 MG storage tank. Both wells are opened and closed simultaneously.

Figure 4-2 illustrates the pressure fluctuations that occur at the Shell #1 and Shell #2 wellheads during a typical well operation cycle. The well operation cycle was 50 minutes of open artesian flow followed by 60 minutes of closed recovery. Cycle duration vary depending on demands and tank water levels. Specific capacity values over a 1 hour
flow cycle for Shell #1 and Shell #2 are 1.3 and 3.9 gallons per minute per foot of drawdown (gpm/ft), respectively.

From April 14 - 19, 2005, Shell #1 was shut-in and the wellhead pressure was monitored at this well for 5 days. During this time, Shell #2 was operated in a typical manner as described previously. Figure 4-3 illustrates the pressure fluctuations that occur at Shell #1 when Shell #2 is cycling on/off at an average flow of 970 gpm. The following observations can be made:

- Over the 5 day shut-in period, Shell #1 recovered 3.6 feet to a maximum recorded wellhead pressure of 225.6 feet (97.7 psi); and
- Artesian flow from Shell #2 causes approximately 2.3 feet (1.0 psi) of drawdown at Shell #1 during a 50 minute operation cycle. This clearly shows the hydraulic connection between Shell #1 and Shell #2 via the wells proximity and common completion in the Madison Limestone.

From April 19 – 20, 2005, Shell #1 remained shut-in and the wellhead pressure was monitored at Shell #2 during its normal operating cycle. Figure 4-4 illustrates the pressure fluctuations that occur at Shell #2 under these conditions. The maximum and minimum wellhead pressures (294 feet and 46 feet, respectively) are slightly lower than what was observed previously at Shell #2 (see Figure 4-2), most likely due to the more frequent cycling on/off of Shell #2 during this period.

4.5 Results of Pump Tests at Shell #1

From April 20 – 28, 2005, Wyoming Groundwater and Weston Engineering, Inc. conducted a 7-day, 450 gpm, constant rate pump test at Shell #1. Weston Engineering, Inc. provided contractor services related to wellhead modifications, installation/removal of a temporary pump, power, water conveyance, and well disinfection. Wyoming Groundwater was responsible for test design, pre-test monitoring, water level/water quality monitoring, and data analysis during the test. The project notebook contains hard copy of all test data.

Water levels in the pumped well, Shell #1, were measured and recorded using a 250 psi transducer set above the pump and a Hermit 1000 C Data Logger. A temporary
pump was set at approximately 500 feet. An air line was installed downhole at the same depth as the transducer to verify transducer values and provide a back-up in case of transducer or data logger failure. During all tests, the transducer and data logger provided accurate data as verified by air line values, field calibration, and set depth calculations. Pump rates were measured using a manometer on a 5 x 6 inch orifice pipe. An on-site generator provided power to an 8-inch diameter 75 horsepower 7-stage submersible pump. The wellhead was disconnected from the piping to the storage tank, and water from the test was conveyed by aluminum pipe to the High Line irrigation ditch.

Wellhead pressures at the observation well, Shell #2, were measured and recorded using a 250 psi transducer set in the wellhead pressure gage port and a Hermit 1000 C Data Logger. During all tests, the transducer and data logger provided accurate data as verified by field calibration and pressure gage comparison. Changes in artesian flow from Shell #2 were monitored using the digital readout of the in-line flow meter and disk chart recorder located in the chlorination building.

After the completion of well testing activities, Shell #1 was disinfected on May 3, 2005, by running a bailer filled with 12 pounds of hypochlorite tablets (65% available chlorine) up and down the well from 0 to 1,800 feet until all tablets were dissolved. The well was shut-in for 7 days and subsequent samples were negative (absent) for total coliform and E-Coli (Appendix C).

4.5.1 Shell #1 Step Test
On April 20, 2005, a step-test was conducted using three steps of 100 minute duration at pump rates of 350, 450, and 490 gpm. From the step-test data it was determined that 450 gpm was an appropriate pump rate for a 7-day test.

4.5.2 Shell #1 Pump Test at 450 gpm – Shell #1 Pump Well
On April 21, 2005, a constant rate discharge pump test was started at a pump rate of 450 gpm and maintained continuously for 168 hours (7 days). There were no interruptions or significant variations in pump rate.

The test was started under flowing artesian conditions (approximately 250 gpm open flow) rather than under ideal conditions of the well being shut-in. In addition to the
difficulties of sealing the wellhead under high pressure, ideal test conditions were not necessary because the objective was to determine well performance, not detailed aquifer analysis. Regardless, the non-ideal starting conditions did not likely affect the magnitude or long-term trend of drawdown. Estimates of total drawdown and specific capacity include the drawdown associated with the observed maximum shut-in pressure of 226 feet (97.7 psi).

Figure 4-5 shows the time-drawdown data from Shell #1 while being pumped at 450 gpm for 7 days. Drawdown values are relative to the wellhead diverter (approximately 1 foot below wellhouse floor) and because the test was started under flowing conditions, these values also represent the approximate depth to water in the well. After 7 days of continuous pumping, the depth to water was 290 feet. However, the total head decline caused by pumping was 516 feet (i.e., 290’ + 226’ shut-in pressure). The calculated specific capacity of the well is 0.87 gpm per foot of drawdown (i.e., 450 gpm/516 ft. of drawdown).

The drawdown data exhibits a consistent rate of drawdown of 20 feet per log cycle from 70 to 10,000 minutes. The two small data steps that occur at elapsed time 1,333 and 3,378 minutes were caused by slight adjustments to the pump rate. No negative boundaries were encountered during the test and the rate of drawdown was stable. Extrapolation of the straight-line drawn through the late-time drawdown data indicates that an additional 20 feet of drawdown would occur if continuous pumping was extended for another 62 days (i.e., one additional log cycle).

Limited recovery data was collected immediately after pump test termination on April 28, 2005. Only 10 minutes of recovery data were collected before water began to discharge from the wellhead diverter.

In summary, the constant rate pump test demonstrated that Shell #1 can be pumped continuously at a rate of 450 gpm with a depth to water on the order of 290 feet. Negative boundaries conditions that can cause accelerated drawdown were not encountered.
4.5.3 Shell #1 Pump Test at 450 gpm – Shell #2 Observation Well

The wellhead pressure and artesian flow from Shell #2 was monitored to determine the hydraulic impacts at Shell #2 during pumping at Shell #1. Throughout the pump test, Shell #2 was operated as needed to meet the Town’s water demands which amounted to artesian flow cycle durations of approximately 74 minutes-on /55 minutes-off.

Figure 4-6 shows the pattern of wellhead pressure at Shell #2 during the pump test. Wellhead pressure fluctuates approximately 225 feet in response to the frequent cycling of open well/shut-in well conditions. Superimposed on the pattern of pressure fluctuation caused by Shell #2 operation is the drawdown caused by pumping Shell #1 that can be seen by the gradual downward trend of shut-in pressure throughout the test. After 7 days of pumping, the wellhead pressure (head) at Shell #2 had decreased by approximately 18 feet (7.8 psi). The trend of head decline caused by pumping can be illustrated simply by plotting the highest pressure value recorded during each pumping cycle as shown on Figure 4-7. A straight-line can be fit to the semi-log plot of time-drawdown data from 2,000 to 10,000 minutes.

The decline in pressure at Shell #2 corresponds with a decline in artesian flow from the well. Each day during the pump test, a flow cycle at Shell #2 was monitored for cycle duration, instantaneous flow rate, and total flow. Table 4-1 lists the results of artesian flow monitoring at Shell #2 and Figure 4-8 provides a plot of the data. Pumping 450 gpm at Shell #1 caused a 63 gpm reduction in artesian flow from Shell #2 by the end of the 7-day pump test. Total artesian flow reduction at Shell #2, as result of pre-test artesian flow, step tests, and the 7-day pump test at Shell #1, was on the order of 78 gpm. A reasonable straight-line can be fit to the semi-log plot of time-flow data as shown on Figure 4-9 although there are sequential flow measurements that indicate no change in artesian flow.

The decline in artesian flow from Shell #2 over an extended period of continuous pumping (i.e., > 7 days) at Shell #1 can be estimated by extrapolating the straight-line shown in Figure 4-9. Artesian flow may decline up to 62 gpm per log cycle such that over a 69 day period of continuous pumping of Shell #1 at 450 gpm, there may be a 140 gpm (i.e., 78 gpm + 62 gpm) reduction in the artesian flow from Shell #2. This estimate
probably represents a maximum magnitude (i.e., conservative) of artesian flow reduction over a 69 day period.

4.5.4 Potential Gain in Production at the Shell (Trapper) Wells

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. Using pump test results, 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 continuous pumping, the total net gain in production would be approximately 190 gpm (i.e., 450 gpm – 180 gpm – 78 gpm). Pumping continuously over longer time periods would cause additional flow declines at Shell #2 that can be estimated by the semi-log extrapolation shown on Figure 4-9. For example, if Shell #2 were to be pumped continuously at 450 gpm for 69 days, the artesian flow from Shell #2 may decline an additional 62 gpm and the production gain may decline to 128 gpm (i.e., 190 – 62 gpm). Actual production gains will depend on pump rate, pumping duration, artesian flow cycles, and aquifer recharge/seasonal variations in aquifer head.

Shell #1 could be pumped at rates greater than 450 gpm with associated increased cost, increased pumping depth to water, and reductions in artesian flow from Shell #2. Potential production gains can be estimated using pump test data (e.g., specific capacity and artesian decline per pump rate at Shell #2).

4.5.5 Water Quality

On April 28, 2005, at the end of the 450 gpm pump test, a water sample was collected and analyzed by Energy Laboratories in Casper, Wyoming. Table 4-2 lists the results of the analysis, and analytical data sheets are provided in Appendix C. Parameter concentrations in this sample are similar to, but slightly lower, than concentrations in a sample collected on April 30, 1984. The water quality satisfies EPA standards for drinking water. The only objectionable characteristic is that the water is very hard (i.e., > 180 mg/L as CaCO₃).
4.6 Shell #1 Downhole Camera Survey

On May 3, 2005, a downhole camera survey was performed at Shell #1 by Weston Engineering, Inc. after the pump test and before well disinfection. The camera had downview and sideview capabilities, and the survey was performed under flowing artesian conditions. The objective of the camera survey was to inspect the condition of the casing and open hole interval to total depth of 3,050 feet. Rock obstructions and potentially unstable hole from 1,798 to 1,800 feet associated with a casing separation at 1,791 to 1,798 feet prevented advancement of the camera beyond 1,800 feet. A detailed log of the camera survey is provided in Appendix C. The Town and WWDC were provided VHS and DVD copies of the camera survey.

Casing and welded joints appear to be in good condition with the exception of slight gaps in joints at 729.4 and 1,185.2 feet. Very little calcite scale was observed on the interior of the casing. This is in contrast to the abundant calcite scale observed in Shell #3 during a camera survey conducted in May 2002.

As mentioned in the Morrison-Maierle (1986) report, the casing had separated at 1,810 to 1,815 feet as indicated by the geophysical log. In the downhole camera survey, the casing separation was observed from 1,791 to 1,798 feet below the wellhouse floor. The separated casing exposes a 7-foot section of Amsden Formation. The sidewall is rough, ragged, and unstable with large rock fragments protruding from the sidewall.

4.7 Summary of Shell #1 Testing

The pump test at Shell #1 demonstrated the following:

- Shell #1 can be pumped at rates significantly higher than the natural artesian flow from the well. If pumped continuously for an extended time period (e.g., 7 to 70 days) at a pump rate of 450 gpm, the depth to water in Shell #1 is on the order of 300 feet;

- Pumping Shell #1 causes a simultaneous decline in artesian flow from Shell #2. After 8 days testing (step and constant rate tests) at 450 gpm, the artesian flow at Shell #2 declined approximately 78 gpm; and

- Potential net production gains from the Shell #1/Shell #2 system is on the order of 130 to 190 gpm (assuming 450 gpm pump capacity) depending on
the pump rate, duration of continuous pumping, and wellfield operation history.
TABLES AND FIGURES
Table 4-1: Artesian Flow Data from Shell #2 During the Shell #1 Pump Test  
Greybull Wells Rehabilitation, Level II, Study

<table>
<thead>
<tr>
<th>Date</th>
<th>Start Time</th>
<th>Run Time</th>
<th>Total Flow Production</th>
<th>Avg. Flow Rate</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>04/14/05</td>
<td>1042</td>
<td>62</td>
<td>58,000</td>
<td>950</td>
<td>Pre-test estimate</td>
</tr>
<tr>
<td>04/21/05</td>
<td>1741</td>
<td>69</td>
<td>63,000</td>
<td>935</td>
<td>Affected by 4/20 step test and flow</td>
</tr>
<tr>
<td>04/22/05</td>
<td>1307</td>
<td>72</td>
<td>65,000</td>
<td>913</td>
<td></td>
</tr>
<tr>
<td>04/23/05</td>
<td>1656</td>
<td>82</td>
<td>73,000</td>
<td>890</td>
<td></td>
</tr>
<tr>
<td>04/24/05</td>
<td>1830</td>
<td>73</td>
<td>65,000</td>
<td>890</td>
<td></td>
</tr>
<tr>
<td>04/25/05</td>
<td>1756</td>
<td>78</td>
<td>69,000</td>
<td>885</td>
<td></td>
</tr>
<tr>
<td>04/26/05</td>
<td>1454</td>
<td>70</td>
<td>61,000</td>
<td>871</td>
<td></td>
</tr>
<tr>
<td>04/28/05</td>
<td>0957</td>
<td>78</td>
<td>68,000</td>
<td>872</td>
<td></td>
</tr>
<tr>
<td>05/10/05</td>
<td>2134*</td>
<td>79*</td>
<td>70,000*</td>
<td>886*</td>
<td>Shell #1 shut-in for 7 days</td>
</tr>
<tr>
<td>05/12/05</td>
<td>0754</td>
<td>45</td>
<td>40,000</td>
<td>889</td>
<td>Shell #1 artesian flow = 180 gpm</td>
</tr>
</tbody>
</table>

*: Estimated values because of approximate start time
Table 4-2: Water Quality Analyses from Shell #1  
Greybull Wells Rehabilitation, Level II, Study

<table>
<thead>
<tr>
<th>Parameter, mg/L</th>
<th>Sample Date</th>
<th>End of Pump Test Sample Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbonate as CO₃</td>
<td>4/30/1984*</td>
<td>04/28/05</td>
</tr>
<tr>
<td>Bicarbonate as HCO₃</td>
<td>250</td>
<td>223</td>
</tr>
<tr>
<td>Calcium</td>
<td>50</td>
<td>45</td>
</tr>
<tr>
<td>Chloride</td>
<td>19</td>
<td>1</td>
</tr>
<tr>
<td>Fluoride</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>Magnesium</td>
<td>28</td>
<td>25</td>
</tr>
<tr>
<td>Nitrate + Nitrite as N</td>
<td>0.39</td>
<td>0.5</td>
</tr>
<tr>
<td>Potassium</td>
<td>&lt; 1</td>
<td>1.2</td>
</tr>
<tr>
<td>Sodium</td>
<td>11</td>
<td>3.4</td>
</tr>
<tr>
<td>Sulfate</td>
<td>17</td>
<td>20</td>
</tr>
<tr>
<td>Silica</td>
<td>1.4</td>
<td>N.A.</td>
</tr>
<tr>
<td>Conductivity, umhos/cm</td>
<td>342</td>
<td>404</td>
</tr>
<tr>
<td>pH, s.u.</td>
<td>7.3</td>
<td>8.01</td>
</tr>
<tr>
<td>Field Temperature, °C/°F</td>
<td>14/57</td>
<td>16.6/62</td>
</tr>
<tr>
<td>Total Dissolved Solids, 180 C</td>
<td>253</td>
<td>215</td>
</tr>
<tr>
<td>Total Dissolved Solids, calc.</td>
<td>377</td>
<td>319</td>
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<tr>
<td>Hardness, as CaCO₃</td>
<td>240</td>
<td>215</td>
</tr>
<tr>
<td>Total Suspended Solids, 105 C</td>
<td>N.A.</td>
<td>1.3</td>
</tr>
<tr>
<td>Turbidity, NTU</td>
<td>N.A.</td>
<td>0.12</td>
</tr>
<tr>
<td>Gross Alpha, pCi/L</td>
<td>0 +/- 2</td>
<td>8.3 +/- 0.8</td>
</tr>
<tr>
<td>Gross Beta, pCi/L</td>
<td>2 +/- 3</td>
<td></td>
</tr>
<tr>
<td>Radium 226, pCi/L</td>
<td>0.7 +/- 0.6</td>
<td>1.9 +/- 0.5</td>
</tr>
<tr>
<td>Radium 228, pCi/L</td>
<td>N.A.</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Radium 226 + 228, pCi/L</td>
<td>N.A.</td>
<td>1.9 +/- 0.5</td>
</tr>
<tr>
<td>Uranium, mg/L</td>
<td>0.003</td>
<td>0.007</td>
</tr>
<tr>
<td>A/C balance, %</td>
<td>N.A.</td>
<td>3.28</td>
</tr>
</tbody>
</table>

*: Data from Morrison-Maierle (1986)  
N.A. = Not Analyzed
SHELL #2 NOTES:
- Open hole in Madison Limestone and Bighorn Dolomite
- Amsden Fm. Caving/Bridges: 1,681-1,751'
- 1985 flow = 1,090 gpm, 797 gpm (73%) Bighorn, 293 gpm (27%) Madison
- 161 psi shut-in (Sept. 1985)

SHELL #1 NOTES:
- Bighorn Dolomite: no yield
- Open hole in Madison Limestone
- 1985 flow = 224 gpm; 143 psi shut-in
- Casing separation: 1,810-1,815'

NOTE:
All well footages are depth relative to ground.

FIGURE 4-1
Shell #1/Shell#2
Well Diagrams
Greybull Wells Rehabilitation, Level II, Study

WELL DATA SOURCE: MORRISON - MAIERLE (1986)
Figure 4-2: Shell #1 and Shell #2 Operation Cycle, April 14, 2005
Shell #1 = 180 gpm artesian flow    Shell #2 = 950 gpm artesian flow
Greybull Wells Rehabilitation, Level II, Study

Data Notes:
Operation Cycle: 50 mins on / 60 mins off
Shell #1 Max. / Min. Pressure: 222' (96 psi) / 82' (35 psi)
Shell #2 Max. / Min. Pressure: 296' (128 psi) / 54' (23 psi)
Shell #1 Specific Capacity = 180 gpm / 140' = 1.3 gpm/ft.
Shell #2 Specific Capacity = 950 gpm / 242' = 3.9 gpm/ft.
Figure 4-3: Shell #1 Wellhead Pressure with Shell #1 Shut-In and Shell #2 Flowing at 970 gpm; April 14 - 19, 2005
Greybull Wells Rehabilitation, Level II, Study

High pressures occur when Shell #2 is closed
Low pressures occur when Shell #2 is open
Figure 4-4: Shell #2 Wellhead Pressure with Shell #1 Shut-In and Shell #2 Flowing at 970 gpm; April 19 - 20, 2005
Greybull Wells Rehabilitation, Level II, Study

Note: Shell #1 is closed
Figure 4-5: Shell #1 Time-Drawdown Data From 7-Day, 450 gpm, Pump Test at Shell #1, April 21 - 28, 2005, Greybull Wells Rehabilitation, Level II, Study

- Elapsed Time, min.
- Drawdown Relative to Diverter, ft. (Depth to Water)

Specific Capacity = 450 gpm / 516 ft
S.C. = 0.87 gpm/ft. of drawdown

\[ \Delta s \text{ over 1 log cycle} = 20 \text{ ft.} \]

Note: Add 226 ft (97.8 psi shut-in pressure) to drawdown values to obtain total head decline caused by pumping

Slight pump rate adjustments
Figure 4-6: Shell #2 Wellhead Pressure During Pump Test at Shell #1, April 21-28, 2005

Shell #1 = 450 gpm (pumping)   Shell #2 = 935 to 871 gpm (artesian flow)

Greybull Wells Rehabilitation, Level II, Study

Test Start: Max./Min. Pressure: 288' (124 psi) / 57' (25 psi)
Test End: Max./Min. Pressure: 270' (117 psi) / 50' (22 psi)
Pressure (Head) Change: 18' (7.8 psi)
Figure 4-7: Maximum Wellhead Pressures at Shell #2 (Operation Cycle) During Pump Test at Shell #1, April 21 - 28, 2005
Greybull Wells Rehabilitation, Level II, Study

Wellhead Pressure, ft.

Δs over 1 log cycle = 16 ft.
Figure 4-8: Shell #2 Average Artesian Flow During a Well Operation Cycle, April 21 - 28, 2005
Shell #1 Pumping at 450 gpm, Greybull Wells Rehabilitation, Level II, Study

Approximate pre-test artesian flow rate from Shell #2
Artesian flow rate just prior to pump test start
April 21, 2005

Decline in artesian flow from Shell #2 During Test = 63 gpm
Figure 4-9: Shell #2 Artesian Flow Decline During the Shell #1 Pump Test at 450 gpm
April 21 - 28, 2005, Greybull Wells Rehabilitation, Level II, Study

Artesian Flow, gpm

Elapsed Time, min.

Δgpm over 1 log cycle = 62 gpm
CHAPTER 5
WELLFIELD OPERATION AND PERFORMANCE

With the possibility of obtaining additional water supplies by pumping, an inspection of the current operation strategy and production of the Shell #1/#2 system and Shell #3 is warranted. The Town’s SCADA and data telemetry system provide real time well production data; however, data manipulation and archiving is incomplete. Consequently, the review and reduction of well production data was limited to well production field logs and annotated 7-day disk charts that continuously record well production. Well production data inventory tables are provided in Appendix D of Volume II.

5.1 Operation and Performance of Shell #3

In 2004, the Shell #3 well provided approximately 17% of the total water supply. The Shell #3 well is allowed to flow continuously by adjusting the Two-Bit valve in the transmission pipeline so that a relatively stable water level is maintained (i.e., input = output) in the adjacent 0.1 MG storage tank. Shell #3 operates with a wellhead pressure of approximately 9 to 12 psi that reflects the pressure generated by the water column in the adjacent storage tank.

As shown in Figure 5-1, during 2004, Shell #3 provided a constant monthly production of approximately 5.13 million gallons and an average production of 117 gpm throughout the year. In the latter part of 2004 and early 2005, artesian flow ranged from 110 to 116 gpm. Subsequent to well rehabilitation, from October 2005 to October 2006 the artesian flow from Shell #3 has ranged from 125 to 150 gpm during continuous operation (i.e., well has not been shut-in) at 11 psi backpressure. When Shell #3 is shut-in, and the aquifer allowed to recover, higher flow rates will occur during subsequent flow periods.

Because Shell #3 is operated continuously, there are not much data on shut-in pressure. The shut-in pressures recorded during this study (62.8 psi) are similar to, but slightly lower than, the shut-in pressure of 68 psi recorded in April 1997.
5.2 Operation and Performance of Shell #1 and Shell #2

In 2004, the Shell #1 and Shell #2 (aka Trapper) wells provided approximately 83% of the total water supply. Artesian flow from the wells is cycled open/closed automatically (via in-line valves at the chlorination building) in response to a change of 1.5 feet in the adjacent 0.35 MG storage tank. Production from these wells is variable in response to demand as illustrated in Figure 5-1. In 2004, the average annual production from the Shell #1/#2 wells, if operated continuously, was 551 gpm.

In the winter months (October to March) when demand is low, the Shell #1/#2 wells are open (i.e., flowing) approximately 25% to 40% of the time. In March 2005, the combined production from the Shell #1/#2 wells during a typical flow cycle was approximately 1,140 gpm.

In the summer months (May to September), the wells are open between 50% to 98% of the time and occasionally must be allowed to flow continuously for 1 to 2 days to keep up with demand. In 2005, production from a typical flow cycle during the summer months of June, July, and August gradually declined from 1,140 gpm in the spring, to a low of 920 gpm by mid-August.

In general, the instantaneous combined production from Shell #1 and Shell #2 is largely dependent 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 much lower instantaneous production on the order of 950 gpm.

Wellhead shut-in pressures at Shell #1 and Shell #2 were reviewed to determine if there have been any noticeable changes in aquifer head with time. Table 5-1 lists wellhead shut-in pressures measured in 1985, 1995, and 2005. From 1985 to 1995, only slight head changes were observed which allowed Nelson Engineering (1995) to conclude that the previous 10 years of production from Shell #1 and Shell #2 had not resulted in any depletion of the Madison-Bighorn aquifer. Another observation from Table 5-1 during this time period is that the head difference between Shell #1 and Shell #2 increased from 42 feet to 72 feet. The cause for this increase is not known.

From 1995 to 2005, there appears to be a significant head decline of approximately 88 feet (38 psi) at both wells, however, the head difference between the
two wells has remained consistent at approximately 70 feet. If this head decline is real and persists throughout the year, there should be a simultaneous decline in artesian flow from the wells. A detailed inspection of well records may provide insight, but the highly variable conditions of well operation and data inadequacies (i.e., infrequent measurements and comparable pre-measurement conditions) will make the analysis difficult and tenuous.

5.3 Anticipated Production with Pumping Systems

Pump test results were used to provide current estimates of winter and summer production if pumps are installed in Shell #3 and Shell #1 (Table 5-2). Pump systems in these two wells could provide a total supply on the order of 1,770 gpm in the winter and 1,610 gpm in the summer. These estimates are an anticipated instantaneous production under current well operation strategies. These estimates are based on the following assumptions and conditions.

- 2005 demands and well production records
- 7 day period of continuous pumping at Shell #1
- Pump capacity of 450 gpm
- Average production during a typical operation cycle of artesian flow at Shell #1 and Shell #2

Pumping systems in Shell #3 and Shell #1 will provide the Town more operational flexibility to meet demands and provide the opportunity for wells/aquifer to recover seasonally. For example, Shell #3 could be pumped during January-March to meet wintertime demands that are typically about 400 gpm (Figure 5-1) and the Shell #1/#2 wells allowed to recover. During April-June and October-December, demands could be met using the combined artesian flow from Shell #1/Shell #2/Shell #3; Shell #3 could be rested during this period to the degree possible. Peak demands during July-September could be met by pumping Shell #1 and Shell #3, and artesian flow from Shell #2.
TABLES AND FIGURES
<table>
<thead>
<tr>
<th>Well</th>
<th>Date</th>
<th>Shut-in Pressure</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ft. (psi)</td>
<td></td>
</tr>
<tr>
<td>Shell #1</td>
<td>Sept. 1985</td>
<td>330.3 (143)</td>
<td>Morrison-Maierle (1986)</td>
</tr>
<tr>
<td></td>
<td>July 1995</td>
<td>312.8 (135.4)</td>
<td>Nelson Eng. (1995); 12 hours shut-in</td>
</tr>
<tr>
<td></td>
<td>April 2005</td>
<td>225.7 (97.7)</td>
<td>5 days shut-in</td>
</tr>
<tr>
<td></td>
<td>July 1995</td>
<td>385.1 (166.7)</td>
<td>Nelson Eng. (1995); 12 hours shut-in</td>
</tr>
<tr>
<td></td>
<td>April 2005</td>
<td>296 (128.1)</td>
<td>Maximum pressure during well operation cycle</td>
</tr>
</tbody>
</table>
Table 5-2: Comparison of Current Artesian Production With Estimated Pump System
Greybull Wells Rehabilitation, Level II, Study

<table>
<thead>
<tr>
<th></th>
<th>Winter</th>
<th>Summer</th>
<th>Winter</th>
<th>Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell #1/#2</td>
<td>1,130</td>
<td>970</td>
<td>1,320**</td>
<td>1,160**</td>
</tr>
<tr>
<td>Shell #3</td>
<td>150</td>
<td>150</td>
<td>450</td>
<td>450</td>
</tr>
<tr>
<td>Totals</td>
<td>1,280</td>
<td>1,120</td>
<td>1,770</td>
<td>1,610</td>
</tr>
</tbody>
</table>

* Assumed pumping rate of 450 gpm
** Production estimates based on 7 days of continuous pumping
Figure 5-1: 2004 Monthly Well Production, Town of Greybull
Greybull Wells Rehabilitation, Level II, Study

2004 Average Q from Shell #3 = 117 gpm
2004 Average Q from Shell #1/#2 = 551 gpm
CHAPTER 6
WATER DEMAND AND SUPPLY

6.1 Introduction

Previous water planning studies have presented water demand projections for the Greybull water supply service area (Nelson Engineering, 1995; Engineering Associates, 1998). The present service area includes the Town of Greybull and rural users east and west of Greybull. Of particular interest to this Level II study are the water demands associated with rural users east of the town’s 1.0 million gallon (MG) water storage tank, including the community of Shell. These users obtain their water supply directly from taps in the Greybull Water Transmission Pipeline (GWTP) system.

Previously published water demand projections were based on forecasted service area populations and per capita water use rates derived from actual water use records. In addition, the system’s most recent water planning document (Engineering Associates, 1998) is based on water demand projections through the year 2025.

One purpose of this Level II study was to review and update the existing water demand forecasts and extend the forecasts to a new planning horizon of 2030 (25 year).

6.2 Population Forecast

Census data and forecast estimates compiled by the State of Wyoming Department of Administration and Information were examined, and are presented on Table 6-1 and Table 6-2. These data suggest that Greybull will not experience any significant growth through the year 2020. Despite this essentially flat population projection, and presumably corresponding water demand, it is wise to provide a reasonable amount of excess system capacity (i.e., margin of safety) in water supply systems to protect against unanticipated demand changes. The following paragraph describes the assumptions used by Engineering Associates (1998). The assumptions are reasonable for planning and we have used them in this Level II study.

Growth factors of 0.6% for Greybull and 1.0% for the rural water users were used to forecast population for the service area. The rural growth rate is slightly higher due to the greater availability of land for development (Engineering Associates, 1998).
1 shows the projected populations based on the most recent data available, Engineering Associates (EA) estimation of 745 rural water users in 1997, and the US Census data of 1,815 residents in Greybull in 2000. To estimate the 2000 population, EA assumed a 0.6% growth rate for the town between 1997 and 2000. However, census data shows that the population actually decreased slightly during this time. Current estimates presented here were based upon the census data. The total population growth of 625 persons during the planning horizon equals 24% of the 1997 estimated population.

6.3 Water Demand

To forecast water demand, per capita water demands were applied to the population projections. The per capita water demands developed by EA were used and are reasonable for this Level II study. The Town’s water demand of 272 gallons per capita day (gpcd) and rural water demand of 195 gpcd resulted in the water demands presented in Table 6-1 and Table 6-2. Peaking factors of 3.0 and 4.3 were applied to the average day demand to obtain the peak day demand and peak hour demand, respectively (Engineering Associates, 1998).

In the 1998 EA work, about 50% of the water demand estimated for rural users was assigned to users along the GWTP. For this Level II study, we have assumed the same distribution of water use. Table 6-3 is presented to clarify our assumptions regarding the planning horizon design demands for the GWTP and source water supplies of Greybull.

As part of this Level II study, the Greybull Chamber of Commerce was consulted regarding the possibility of significant commercial or industrial development in the area within the planning horizon. An ethanol plant is scheduled for construction that will require a reasonable large process water supply. However, the water supply for this facility will likely come from water rights in the Greybull River (Ron Vanderpool, pers. comm., September 2005). The conclusion was that there is no compelling reason to consider the impact of an unusually large water demand increase beyond that caused by a modest population increase. Additionally, Joanne Garnett of Worthington, Lenhart and Carpenter in Casper, Wyoming, agreed with this conclusion, based on that firm’s community planning study of the area (pers. comm., August 2005).
6.4 Water Supply Needs Analysis

As presented in the previous section, the planning horizon water demands, presented on Table 6-3, are nearly 25% more than present day demands. To meet the demands, the water supply sources need to be of sufficient number and production quantity to comply with Wyoming Department of Environmental Quality (WDEQ) regulations. Chapter 12, Section 9, (b), (i) of the WDEQ regulation reads:

“Number and Capacity: The total developed groundwater source, along with other water sources, shall provide a combined capacity that shall equal or exceed the design maximum daily demand. A minimum of 2 wells, or 1 well and finished water storage equal to twice the maximum daily demand shall be provided. Where 2 wells are provided, the sources shall be capable of equaling or exceeding the design average daily demand with the largest producing well out of service.”

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 (Table 6-3). Therefore, the required future supply enhancement is a minimum of 420 gpm. Also, with the largest well (Shell #2) 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 (Table 6-2). 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.

6.5 Water Supply Summary

Currently, the Town of Greybull obtains water exclusively from three flowing artesian wells that can provide 1,120 to 1,280 gpm in the summer and winter, respectively (Table 5-2). This Level II study has determined that 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 (Table 5-2).

The Town of Greybull is an active participant in the Big Horn Regional Water System (BHRWS) and will be receiving additional water supplies when the system infrastructure is constructed. In early 2006, the Town received an additional 180 gpm from the South Big Horn County Joint Powers Board via an 8-inch pipeline that crosses the Greybull River (i.e., the Greybull River Crossing). This 180 gpm is a short-term temporary supply intended to help relieve the Town of supply shortages over the next 3 to 5 years.

BHRWS’s design allocation to Greybull is 580 gpm which is anticipated to be available by the end of 2008. A 12-inch pipeline installed as part of BHRWS construction schedule (Element 9) will be connected to the Town system near the west tank and will have the capacity to provide 900 gpm. Greybull is allocated 580 gpm of the 900 gpm and the remainder is designated to the communities of Otto and Burlington which have recently decided to participate in the BHRWS. If Otto and Burlington’s participation in the BHRWS were to change, Greybull may have the opportunity to use the entire 900 gpm (Susan Holmes, HKM, pers. comm., August 2005).

An important point is that the BHRWS is not intended to be a primary source of water for the Greybull, but rather, as a secondary (redundant) supply to be used in case of emergency or unforeseen demand. Greybull will pay for the tap into and use of the BHRWS water supply.

To summarize, the installation of pumping systems appears to be a feasible enhancement to the Town’s primary 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 BHRWS will provide supply redundancy in the event of emergencies (e.g., pipeline or well failure) and unforeseen increases in demand.
TABLES AND FIGURES
### Table 6-1: Water Demand for the Town of Greybull and Rural Users, Million Gallons per Day (MGD). Greybull Wells Rehabilitation, Level II, Study

<table>
<thead>
<tr>
<th>Year</th>
<th>Population</th>
<th>Average Day Demand (MGD)</th>
<th>Peak Day Demand (MGD)</th>
<th>Peak Hour Demand (MGD)</th>
<th>Population</th>
<th>Average Day Demand (MGD)</th>
<th>Peak Day Demand (MGD)</th>
<th>Peak Hour Demand (MGD)</th>
<th>Population</th>
<th>Average Day Demand (MGD)</th>
<th>Peak Day Demand (MGD)</th>
<th>Peak Hour Demand (MGD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>1,836*</td>
<td>0.52</td>
<td>1.55</td>
<td>2.22</td>
<td>745*</td>
<td>0.15</td>
<td>0.44</td>
<td>0.63</td>
<td>2,581*</td>
<td>0.66</td>
<td>1.99</td>
<td>2.85</td>
</tr>
<tr>
<td>2000</td>
<td>1,815*</td>
<td>0.51</td>
<td>1.53</td>
<td>2.20</td>
<td>767</td>
<td>0.15</td>
<td>0.45</td>
<td>0.65</td>
<td>2,582</td>
<td>0.66</td>
<td>1.98</td>
<td>2.84</td>
</tr>
<tr>
<td>2005</td>
<td>1,870</td>
<td>0.53</td>
<td>1.58</td>
<td>2.26</td>
<td>806</td>
<td>0.16</td>
<td>0.47</td>
<td>0.68</td>
<td>2,676</td>
<td>0.68</td>
<td>2.05</td>
<td>2.94</td>
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<tr>
<td>2010</td>
<td>1,927</td>
<td>0.54</td>
<td>1.63</td>
<td>2.33</td>
<td>847</td>
<td>0.17</td>
<td>0.50</td>
<td>0.72</td>
<td>2,774</td>
<td>0.71</td>
<td>2.13</td>
<td>3.05</td>
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<tr>
<td>2015</td>
<td>1,985</td>
<td>0.56</td>
<td>1.68</td>
<td>2.40</td>
<td>891</td>
<td>0.17</td>
<td>0.52</td>
<td>0.75</td>
<td>2,876</td>
<td>0.73</td>
<td>2.20</td>
<td>3.15</td>
</tr>
<tr>
<td>2020</td>
<td>2,046</td>
<td>0.58</td>
<td>1.73</td>
<td>2.47</td>
<td>936</td>
<td>0.18</td>
<td>0.55</td>
<td>0.79</td>
<td>2,982</td>
<td>0.76</td>
<td>2.28</td>
<td>3.27</td>
</tr>
<tr>
<td>2025</td>
<td>2,108</td>
<td>0.59</td>
<td>1.78</td>
<td>2.55</td>
<td>984</td>
<td>0.19</td>
<td>0.58</td>
<td>0.83</td>
<td>3,092</td>
<td>0.79</td>
<td>2.36</td>
<td>3.38</td>
</tr>
<tr>
<td>2030</td>
<td>2,172</td>
<td>0.61</td>
<td>1.83</td>
<td>2.63</td>
<td>1,034</td>
<td>0.20</td>
<td>0.61</td>
<td>0.87</td>
<td>3,206</td>
<td>0.81</td>
<td>2.44</td>
<td>3.50</td>
</tr>
</tbody>
</table>

* Denotes Actual Population; others estimated with growth rates 0.6% for Town, 1.0% for Rural

### Table 6-2: Water Demand for the Town of Greybull and Rural Users, Gallons per Minute (GPM). Greybull Wells Rehabilitation, Level II, Study

<table>
<thead>
<tr>
<th>Year</th>
<th>Population</th>
<th>Average Day Demand (GPM)</th>
<th>Peak Day Demand (GPM)</th>
<th>Peak Hour Demand (GPM)</th>
<th>Population</th>
<th>Average Day Demand (GPM)</th>
<th>Peak Day Demand (GPM)</th>
<th>Peak Hour Demand (GPM)</th>
<th>Population</th>
<th>Average Day Demand (GPM)</th>
<th>Peak Day Demand (GPM)</th>
<th>Peak Hour Demand (GPM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>1,836*</td>
<td>359</td>
<td>1,076</td>
<td>1,542</td>
<td>745*</td>
<td>102</td>
<td>305</td>
<td>437</td>
<td>2,581*</td>
<td>460</td>
<td>1,381</td>
<td>1,979</td>
</tr>
<tr>
<td>2000</td>
<td>1,815*</td>
<td>355</td>
<td>1,064</td>
<td>1,525</td>
<td>767</td>
<td>105</td>
<td>314</td>
<td>450</td>
<td>2,582</td>
<td>459</td>
<td>1,377</td>
<td>1,974</td>
</tr>
<tr>
<td>2005</td>
<td>1,870</td>
<td>365</td>
<td>1,096</td>
<td>1,571</td>
<td>806</td>
<td>110</td>
<td>330</td>
<td>473</td>
<td>2,676</td>
<td>475</td>
<td>1,426</td>
<td>2,043</td>
</tr>
<tr>
<td>2010</td>
<td>1,927</td>
<td>376</td>
<td>1,129</td>
<td>1,619</td>
<td>847</td>
<td>116</td>
<td>347</td>
<td>497</td>
<td>2,774</td>
<td>492</td>
<td>1,476</td>
<td>2,115</td>
</tr>
<tr>
<td>2015</td>
<td>1,985</td>
<td>388</td>
<td>1,163</td>
<td>1,667</td>
<td>891</td>
<td>122</td>
<td>365</td>
<td>523</td>
<td>2,876</td>
<td>509</td>
<td>1,528</td>
<td>2,190</td>
</tr>
<tr>
<td>2020</td>
<td>2,046</td>
<td>400</td>
<td>1,199</td>
<td>1,719</td>
<td>936</td>
<td>128</td>
<td>383</td>
<td>549</td>
<td>2,982</td>
<td>527</td>
<td>1,582</td>
<td>2,268</td>
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<tr>
<td>2025</td>
<td>2,108</td>
<td>412</td>
<td>1,235</td>
<td>1,771</td>
<td>984</td>
<td>134</td>
<td>403</td>
<td>577</td>
<td>3,092</td>
<td>546</td>
<td>1,638</td>
<td>2,348</td>
</tr>
<tr>
<td>2030</td>
<td>2,172</td>
<td>424</td>
<td>1,273</td>
<td>1,824</td>
<td>1,034</td>
<td>141</td>
<td>423</td>
<td>607</td>
<td>3,206</td>
<td>565</td>
<td>1,696</td>
<td>2,431</td>
</tr>
</tbody>
</table>

* Denotes Actual Population; others estimated with growth rates 0.6% for Town, 1.0% for Rural
Table 6-3: Planning Horizon (year 2030) Water Demand/Supply Summary
Greybull Wells Rehabilitation, Level II, Study

<table>
<thead>
<tr>
<th></th>
<th>Average Day Demand (ADD) gpm</th>
<th>Maximum Day Demand (MDD) gpm</th>
<th>Peak Hour Demand (PHD) gpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand On the GWTP</td>
<td>71 gpm</td>
<td>212 gpm</td>
<td>303 gpm</td>
</tr>
<tr>
<td>Demand Not on the GWTP</td>
<td>495 gpm</td>
<td>1,485 gpm</td>
<td>2,128 gpm</td>
</tr>
<tr>
<td><strong>Total Demand</strong></td>
<td>565 gpm</td>
<td>1,696 gpm</td>
<td>2,431 gpm</td>
</tr>
</tbody>
</table>

Current Supply Capabilities, gpm
- Shell #1: 180 gpm
- Shell #2: 950 gpm
- Shell #3: 150 gpm

Total: 1,280 gpm
7.1 Introduction

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 pipeline and an evaluation of the hydraulic capability of the Greybull Water Transmission Pipeline (GWTP). In October 2005, a Draft Report for the Level II study was provided to the Greybull Town Council and the WWDC. The Draft Report included a preliminary analysis of the GWTP’s capacity to deliver water as it was presently being operated and a conceptual design for improvements that would allow the GWTP to deliver additional flow to the 1 million gallon (MG) tank. Appendix E of Volume II contains copies of chapters from the Draft Report related to preliminary GWTP analysis.

The Draft Report identified two important conditions: 1) Town operators questioned the structural integrity of the pipeline and 2) preliminary hydraulic modeling results had considerable uncertainty due to assumed model parameters. The hydraulic modeling indicated that adjustments to the pipeline pressure sustaining/reducing valves may be a feasible method to get additional flow to the 1 MG tank under acceptable pipeline pressures.

The Draft Report provided a list of alternatives and cost estimates for improvements to the GWTP. The recommended alternative involved additional pipeline flow tests, surveying, pipeline materials inspection/testing, and hydraulic modeling of the GWTP. The WWDC and Greybull Town Council authorized Wyoming Groundwater to proceed with additional work per the recommended alternative as part of the existing Level II study.

7.2 GWTP History and Operation

The GWTP begins at the Shell #3 well and runs west for 16.5 miles down the Shell Creek Valley to the 1 MG storage tank on the east side of the Bighorn River (Figure 7-1). The GWTP pipeline was originally installed in the late 1930’s as a steel pipeline from the infiltration gallery in Shell Creek (south of Shell #3) to the Town of Greybull.
Due to corrosion, portions of the line were replaced with 12-inch diameter asbestos cement (AC) pipeline in the 1960’s. According to Town records, these spot replacement efforts used 150 psi working pressure class pipe (600 psi burst pressure). 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 rated pipe from 400 to 600 psi burst pressure (T40, T45, and T60). Most of the 14-inch diameter pipe is Class T40, except portions of the line in Scharen Gulch, West Scharen Subdivision, and near the 1 MG storage tank. The locations of 12-inch and 14-inch diameter AC pipe segments along the GWTP are shown on the hydraulic profile of Plate 7-1.

In 1986, the Shell #1 and Shell #2 (aka Trapper) 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. One exception is the valve at the Shell Vault which has only pressure reducing capabilities.

Under current operation, flow control using the Two-Bit and Smith valves can be achieved, but it requires periodic adjustment by Town operators. In the Draft Report (Appendix E), alternative flow control and pipeline solutions were provided, and the Town Council decided to pursue an alternative involving the adjustment/modification of existing valves on the GWTP that included the following list of tasks designed to provide a thorough evaluation of this alternative.

- Pipeline flow test;
- Leak detection tests;
- Valve inspection;
- Pipeline location/elevation survey;
- Service connection mapping;
- Pipeline hydraulic modeling; and
- Pipeline material inspection, testing, and evaluation.
7.3 Pipeline Flow Test

A critical parameter in pipe flow calculations is the frictional resistance of the pipeline material most often expressed by the Hazen-Williams C value. On February 10, 2006, WWC Engineering performed a flow test to provide an estimate of C for the GWTP. Prior to the flow test, pressure transmitters were calibrated and an elevation survey was performed at transmitters and PRV stations critical to the flow test. Pressure transmitter calibration was performed by Automation Electronics field technicians. The elevation survey (Section 7.6) was performed by WWC Engineering.

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.

A technical memo from WWC Engineering describing the pipeline flow test and calculations is provided in Appendix E.

7.4 Leak Detection Testing

On January 25-27, 2006, Utility Technical Services (UTS) conducted a pipeline leak survey of the GWTP from the 1 MG storage tank to the Shell #3 well. The leak detection survey was performed using a noise correlator. Two possible leak noises were detected at the Glen Nelson air-vac and the service line to the Heller Shop. These two leaks were estimated by UTS to have a combined leakage of 6 to 9 gpm. No large leaks were detected in the GWTP by the instruments/technician used in the survey. The UTS field report is provided in Appendix E.

A second method for estimating system leakage was attempted by aggregating the metered water use along the GWTP and comparing that value to the difference of water volumes produced at Shell #1/#2/#3 and delivered to the 1 MG tank. Leakage estimates were substantial and were not thought to be reliable by Town operators. Documentation for this work was not prepared, as it was an informal study.
7.5 **Valve Inspection and Discussions with System Operator**

On February 9, 2006, Mr. John Tedder of Rocky Mountain Valve (RMV) inspected the hydraulic valves in the GWTP. The objective was to examine the current operation of the valves and make preliminary recommendations for pipeline operation improvements. In August and early September 2006, Mr. Tedder visited with Town personnel and WWC Engineering several times, including an additional site visit. Based on the field inspection and discussions with WWC Engineering, Mr. Tedder assisted the project engineer with the conceptual design of proposed valve modifications. A technical memo from WWC Engineering regarding valve inspection/recommendations and the report provided by RMV from field inspections are provided in Appendix E.

7.6 **Pipeline Location and Elevation Survey**

The hydraulic modeling and flow test required accurate horizontal (location) and vertical (elevation) information on GWTP components. In January 2006, WWC Engineering performed a survey of critical GWTP components including storage tanks, wells, pressure reducing valves, transmitters, gauges, and structural features. The work was performed using GPS survey grade equipment with a vertical accuracy of +/- 4 cm and a horizontal accuracy of +/- 2 cm for most of the features. The survey was based on NAV 88 datum with NGS coordinates. Appendix E contains a memo from WWC Engineering that describes the survey work and critical elevation data.

7.7 **Service Connection Mapping**

Service connection mapping involved using GPS survey grade equipment and existing Town survey data to determine the location and elevation of the following features along the GWTP:

- service meter pits;
- point of use (i.e., residence); and
- pipeline appurtenances such as air-vac cans, blow-offs, and valves.

This effort produced a 3-part map that shows pipeline alignment, location/identification of service meter pits, points of use, and estimated current/future
water pressure at pipeline service taps and point of use at individual customers along the GWTP. The maps are included in the project notebook and have been provided to the Greybull Public Works Department. Appendix E contains the data table associated with the maps.

The user of these data should be aware that existing Town survey data, specifically elevations at service meter pits, are not as accurate as the elevation data collected by WWC Engineering. At some locations, elevation differences between the Town and WWC Engineering data were about 20 feet.

The elevation of points of use along the GWTP may be considerably higher or lower than the transmission line service connections. Consequently, the pressure in the GWTP can be a poor estimate of the water pressure at the user’s residence/point of use. This information was used in Section 7.11 to make general comments on static pressure changes at points of use under the recommended modifications to pipeline valves and operation.

### 7.8 Pipeline Hydraulic Evaluation

WWC Engineering performed a hydraulic evaluation of the GWTP. The purpose of the evaluation 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; and
- Provide information (e.g., static and transient pipeline pressures) for the structural evaluation of the pipeline.

The hydraulic evaluation was needed to 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. Plate 7-1 is a plan and profile drawing of the pipeline system. Plate 7-1 also presents the results of the
hydraulic evaluation and the remainder of this chapter makes frequent reference to this exhibit.

7.8.1 Existing GWTP Conditions

Currently, flow control from the wells is achieved via valve adjustment at the Two-Bit PSV and the Smith Valve. When demand in Town and along the line is less than well production, then the tank spills if it is full. If the tank is not full, then spilling may or may not occur depending on the water stage in the tank and the replenishment pattern (difference between demand and supply).

Plate 7-1 presents an estimate of the hydraulic grade line that was observed in July 2005. This hydraulic grade line (HGL) information was compared to the point of use (POU) survey data discussed in Section 7.7 and presented in Table E-1 of Appendix E. The comparison of HGL to POU elevations results in an estimate of the available water service pressure at a given point of use. Plate 7-1 also shows that the flow to the 1 MG tank in July 2005 was about 868 gpm. It is important to note that this flow rate was the result of the operating conditions that the system operator had selected and does not represent the maximum capacity of the pipeline.

7.8.2 Conceptual Design for Future GWTP Conditions

To evaluate possible changes to pipeline operation and configuration, a steady-state hydraulic model was prepared using the EPANET 2.0 software program. Appendix E contains a technical memo that describes the modeling methods and results. The following paragraphs focus on the results presented graphically on Plate 7-1.

For maximum demand conditions, Plate 7-1 presents a HGL showing 1,500 gpm being delivered to the 1 MG tank, while serving 300 gpm of peak demand to Shell Valley water users along the pipeline. This HGL meets the maximum day water delivery requirements for the Town (1,485 gpm) and peak hour requirements (303 gpm) for water users along the line (Table 6-3). This condition was achieved by making set point adjustments to the PRV/PSV valves on the GWTP and by assuming that the Dog Pound Valve would be converted to a modulating valve that would maintain a relatively constant water level in the 1 MG tank. At nearly all locations, this maximum demand
HGL is higher than the July 2005 HGL. This indicates that the proposed modifications and improvements will actually increase operating pressures, except for a few users near the 1 MG tank (see Section 7.11). Appendix E (Table E-1) includes information showing the estimated water service pressures at points of use for the proposed operating configuration.

For the low demand condition, a zero flow HGL is presented on Plate 7-1. This grade line represents the hydraulic condition in the pipeline when demands are absent or very small. This condition might occur at night in winter months. The zero flow HGL shows that pipeline pressures will be higher than any other steady state condition. Appendix E (Table E-1) includes information on water service pressures under the zero flow condition.

7.8.3 Hydraulic Evaluation to Support Structural Evaluation

The third objective of the hydraulic evaluation was to provide pipeline operating pressures, both static and dynamic, to Simpson Gumpertz & Heger, Inc. (SGH) for their structural evaluation of the pipeline presented in Section 7.9. WWC Engineering provided these estimates by performing a steady state hydraulic evaluation, described in the previous section, and a hydraulic transient evaluation. Steady state and transient hydraulic evaluations are documented in Appendix E. The results of both evaluations are shown on Plate 7-1 and discussed in Section 7.9.4.

7.9 Pipeline Material Inspection, Testing, and Evaluation

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. To address these issues, Simpson Gumpertz & Heger, of Waltham, Massachusetts, with assistance from Wyoming Groundwater, performed a condition assessment of the AC pipeline.

The scope of work included the following:

- review of available documents;
- excavation and external examination/field testing of the pipeline at 10 locations;
• collection of pipeline tap and section samples for laboratory testing and evaluation;
• mechanical testing and petrographic analysis of pipeline samples;
• structural evaluation of the pipeline subjected to the combined effects of external loads, internal pressure, and pipe/fluid weights;
• determination of the corrosivity of soil, groundwater, and internal water to the AC pipe;
• evaluation of the quality and condition of the asbestos cement to determine deterioration mechanisms and physical condition; and
• determination of the risk of pipe failure and expected durability of the pipeline for future use.

A report, “Condition Assessment Greybull Water Transmission Pipeline, Greybull, WY” by SGH is provided in Appendix E. The methods and results of the pipeline condition assessment are summarized in this chapter.

7.9.1 Historical Performance of GWTP

To date, the performance of the AC pipe in the GWTP has been good with only one reported pipe failure in 1999 caused by a pressure surge (water hammer) generated by rapid valve adjustment. There was one other instance where the pipeline has been damaged by excavation activities and had to be repaired. With only two failures in 33 years, including one from excavation damage, the failure rate of the GWTP has been about 0.34 breaks per 100 miles per year of service, significantly lower than rates reported in England and Canada (1.5 to 2.5 failures per year for the same length of AC pipeline). Typical pipe repair and maintenance have involved pipeline appurtenances (e.g., air valves, blow-off valves, Dresser couplings, etc.) and not repair of the AC pipe itself.

“Soft” pipe, as indicated by rapid tapping, in the vicinity of the Iowa State University Geology Field Camp has been reported by system operators.
7.9.2 **Pipe Inspection**

The purpose of external inspection of the pipe was to examine the condition of the pipe, collect samples of soil and groundwater, perform non-destructive testing on the pipe, and to remove samples of pipe for testing and analysis. Excavation sites were selected by SGH and Wyoming Groundwater based on the review of local geology, soils, topography, and preliminary results of hydraulic/structural analyses. Excavations were located in some of the worst conditions for the pipe and in other representative conditions. We considered soils corrosive to AC pipe that have high concentration of sulfates, low pH, and high or variable groundwater table in the pipe zone, areas with clayey soil that may result in differential settlements, and areas of high internal pressures. We also selected sites that are dry and have sandy soils. Figure 7-1 shows the location of ten pipeline excavations and Table 7-1 summarizes conditions and data observed/obtained in each excavation.

The pipeline was excavated by a crew from the Greybull Public Works Department. 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. The nondestructive tests were performed to measure relative differences in stiffness of the pipe wall.

The following list summarizes observations and results of pipe external inspections.

- No cracks, delamination, hollow sounding, or other anomalies were observed at pipes in any of the excavation sites. The surface finish was visible on all excavated pipes to a varying degree.

- UPV results for all pipes are within less than 10% (between 70.5 and 73.3 msec), indicating relatively uniform stiffness of the pipe wall, with no significant anomalies in any of the inspected pipes.

- Schmidt hammer results for all pipes range between 33.2 and 44.2 indicating some variation in pipe wall surface stiffness. The lowest readings correlate with observed surface deterioration in petrographic analysis and with operator observations of rapid tapping in the same
general area of the pipeline (i.e., Excavation #11, Iowa State Geology Field Camp).

- Joint collars were observed in four excavations and no anomalies were observed in the collar or the joint.
- Pipe in Excavation #12 had a manufacturers stamp indicating that the pipe was made by Certain Teed as 14-inch FT 40 AC Type II pipe.
- The pipe failure in 1999 at Scharen Gulch (Excavation #3) appears to have failed at or near a joint. The repair includes a short piece of PVC pipe and Dresser couplings. One coupling was exposed during excavation and appears to be in good condition.
- Soil in the excavations ranges from clay/silt to sand with some clay/silt.
- Groundwater occurred in the pipe zone at five of the excavations.
- High to moderate sulfate concentrations occur in soil and groundwater at the west end of the GWTP (i.e., Excavations 1 through 6) in six of the ten excavations.

Appendix E (SGH report) contains laboratory data sheets for groundwater and soil samples collected in the excavations, water samples from the GWTP for analysis of general inorganic parameters and asbestos fibers, and soil sieve analysis.

7.9.3 Pipeline Material Testing

The purpose of material testing was to check the quality and condition of asbestos cement pipe and corrosiveness of the subsurface environment. Pipeline material testing consisted of the following tasks:

- Petrographic analysis of pipeline samples;
- Mechanical testing of AC pipeline samples;
- Classification of soils that surround the pipeline;
- Chemical analysis of soil and groundwater encountered in pipeline excavations; and
- Chemical analysis of water in the pipeline.
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 (Table 7-1, HC-1). Samples included all known pipe classes along the GWTP between the supply wells and the 1 MG storage tank (i.e., 12-inch diameter Class 150 pipes and 14-inch diameter Class T40 and T45 pipes).

Soil classification and chemical analysis of soil/groundwater was performed for samples collected from all pipe excavation sites.

Mechanical testing including three-edge bearing and flexural tests on pipe samples obtained from an abandoned portion of pipeline west of the infiltration gallery beneath Shell Creek (Excavation #12). This pipe was 14-inch diameter Class T40 Type II (sulfate resistant) which is the lowest pressure class and most prevalent pipe along the GWTP.

Pipeline water samples were collected from the Town Shop (Public Works Department) near the 1 MG storage tank, a customer tap (Tn’B Villa in Shell), and from the tap at Scharen Gulch. (Excavation #3).

The results of material testing indicate the following.

- Overall composition and microstructure of the asbestos cement is very good with no evidence of sulfate attack.
- Minor to moderate acid attack exists on the exterior surface of two of seven samples. Depth of physical alteration of the cement paste was less than 1 mm in all but one sample, where it was up to 1.8 mm.
- The range of crushing strength was between 6,621 lb/ft and 7,032 lb/ft, significantly higher than the minimum crushing strength of 3,000 lb/ft specified in ASTM C668 for 14-inch diameter Class T40 pipe.
- Test results indicate maximum circumferential flexural strength of the pipe wall of about 10,000 psi.
- Water in the pipeline is not corrosive to AC pipe and no internal deterioration of the pipe has been observed.
- No asbestos fibers were detected in the sample of water collected at the west end of the pipeline (i.e., Town Shop) which also indicates no internal deterioration of the pipe.
7.9.4 Hydraulic Analysis

Plate 7-1 shows the results of hydraulic analysis of the pipeline at present, and for the proposed future pipeline operation. In present operation of the pipeline, the flow is never stopped; if flow was stopped it would result in a zero flow hydraulic grade line at an elevation of 4,383 feet (i.e., Shell #3 tank elevation). The process of stopping the flow, even slowly over about 20 minutes (i.e., Method 2, Plate 7-1), would increase the maximum hydraulic grade line by up to about 70 feet of hydraulic head. This situation could result in significantly higher pressures (maximum pressure of about 225 psi) than pipe design pressures, and should not be allowed to occur. Sudden closure of valves at the 1 MG tank could result in even higher pressures of about 300 psi that could damage and even rupture the pipeline (i.e., Method 1, Plate 7-1). The only pipe failure to date occurred during a transient pressure event.

In the contemplated future operation after modifications to the valve system, there could be periods of zero flow in the pipeline, typically at night when demand is low and the 1 MG storage tank is full. This would increase the pressure in the pipeline, and the maximum transient pressure would depend on actual modification of the valves and the pressure relief system. For the purpose of structural evaluation of the pipeline, it was assumed that the transient pressure resulting from valve closure would be similar to that resulting from valve closure in the present system.

7.9.5 Structural Evaluation

SGH calculated the factors of safety along the pipeline based on the pipe class, maximum working and working plus transient pressure, and soil loads. AC pipe is designed for combined internal pressure and external load following the empirical load-pressure limit where horizontal and vertical axis intercepts are the burst pressure, and the ultimate three-edge bearing load, respectively. The burst pressure and three-edge bearing loads are specified in AWWA and ASTM standards for AC pipe. For the three-edge bearing load, SGH used the measured three-edge bearing strength for Class T40 pipe, and the maximum load given in the standard for Class 150 pipe. For Class T40 pipe, the design load is given as minimum 3,000 lb/ft, and we used 6,000 lb/ft based on the
measured range of crushing strength between 6,621 lb/ft and 7,032 lb/ft. Class T40 pipe is the most prevalent class of pipe along the pipeline and the lowest strength pipe in the line, and the same strength was used for Class T45 pipe. Soil loads assumed 6 feet of soil cover.

The results of the structural analysis of the GWTP indicate the following.

- For the current maximum pressure in Class T40 pipes, the factor of safety is well within the design envelope. If the flow in the pipeline was stopped by slowly closing the valve at the 1 MG tank, this would result in reduction in safety and the design would be significantly outside the design envelope. If there was a rapid closure of the valve, this would result in higher pressures and lower factors of safety.

- Closure of the valve at the 1 MG tank should be avoided prior to modifications of valves and addition of pressure relief valves along the pipeline. Instantaneous closure of valves would result in maximum working plus transient pressure of about 300 psi and possible rupture as it is very close to design ultimate strength of the pipe.

- For the future maximum pressure after modifications of valves, the design would lie only slightly outside of the transient envelope specified by AWWA C403.

- Assuming future maximum pressure condition and loss of section of 10%, the pipe design would not lie within the design envelope recommended by AWWA C403 for new pipes. Deteriorated pipes (assuming 10% loss of section) would have safety up to 15% below that recommended by AWWA C403 over short areas of the pipeline.

- To protect the AC pipeline from excess surges, future changes in flow need to be designed to keep transient pressures low such that design envelope is not exceeded.
7.10 Conclusions and Recommendations on GWTP Condition and Future Use

Based on the results of exterior inspection, material testing, petrographic and chemical analysis, hydraulic analysis, and pipe structural evaluation, SGH submits the following conclusions.

- There is no systematic deterioration of the AC pipe. There was no evidence of sulfate attack and only minor to moderate acid attack at sporadic 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 is no reason to believe that the failure rate and reliability of the GWTP will not 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.

Based on the results of this study, SGH recommends the following.

- Control of the maximum surge pressure in the pipeline to reduce the risk of pipeline failure. The maximum pressures should not exceed 145 psi.
- In case of future multiple failures of the pipe that show signs of deterioration, consider replacement of over-stressed areas of the pipeline.
- Collect future tap samples and perform petrographic analysis of the samples to supplement the results of this study and determine if there are areas with more degradation than observed thus far.
Based on distress observed on future tap samples and the actual hydraulic transient pressures experienced, re-evaluate the condition of the pipeline within the next ten years.

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

7.11 Service Connection Pressures

Service connection mapping produced an extensive database that Town operators can use to evaluate the location and magnitude of pipeline pressure changes at service taps and points of use along the GWTP that may occur if pipeline valve modifications are instituted (i.e., per Chapter 9 conceptual designs). Appendix E contains Table E-1 and histograms (Figures E-1, E-2, and E-3) that summarize pipeline and point of use water pressures under current and modeled future GWTP operation. Table E-1 and the service connection maps provided to the Town operator are a work-in-progress such that the database and maps will be updated as new data becomes available. It is recommended that the Town operator(s) and the Level II study project engineer have a detailed discussion regarding data presented in Table E-1.

The following general observations can be made regarding the modeled future GWTP operation (i.e., per Chapter 9 conceptual designs) and are best illustrated by inspection of the July 2005, zero flow, and maximum day demand/peak day demand (solid dark line) hydraulic grade lines shown on Plate 7-1:

- Under zero flow conditions, all customers will experience pressure increases;

- Under maximum day demand/peak day demand conditions, some customers will experience pressure increases and some customers will experience pressure decreases; however, there will probably be a net benefit as some customers with current low pressure will experience higher pressure; and
• The most sensitive area along the GWTP is at the west end (Station 820+00 to 870+00 on Plate 7-1), near the 1 MG tank, where pressure decreases are likely to occur during periods of maximum day demand/peak day demand.

7.12 Summary

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. Chapter 9 provides conceptual designs and cost estimates for pumping systems and recommended GWTP modifications.
TABLES AND FIGURES
### Greybull Water Transmission Pipeline Excavation Data, G

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<tr>
<th>Excavation Name</th>
<th>Infiltration</th>
<th>Iowa State Camp</th>
<th>Kerschner</th>
<th>Woodland</th>
<th>West Whaley</th>
<th>Sheldon Gulch</th>
<th>Highway 14 Crossing</th>
<th>Potato Ridge</th>
<th>Scharen Gulch</th>
<th>West Scharen</th>
<th>Frenchy Draw</th>
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<td>91.4</td>
<td>99.2</td>
<td>97.0</td>
<td>76.7</td>
</tr>
</tbody>
</table>

### Soil Chemistry and Physical Properties

- **Chugwater formation**, red shale with occasional gypsum
- **Chugwater formation**, Red Shale with Occasional Gypsum
- **Gypsum Spring Formation**, Corrosive soil
- **Dark grey shale with bentonite; Local bentonite mines in Thermop Shale**
- **Alkali Deposits; Clovery/Thermop contact**
- **Massive grey shale in sandstone with abundant alkali surface deposits; Potentially expansive soil – Bentonite in Thermop Shale**
- **Alkali Deposits & Cody Shale**
- **Alkali Deposits & Cody Shale**
- **Alkali Deposits & Frontier Formation**

### Water Saturation

- **High groundwater, flood irrigated fields, manmade irrigation canals**
- **High groundwater, saturated cond.**
- **High groundwater, heavy irrigation**
- **Near Shell Creek in woodland**
- **Flood irrigated fields, off Whaley Ditch, level ground**
- **Bottom of drainage**
- **Abandoned irrigation lateral crossing nearby**
- **Shallow groundwater, bottom of drainage**
- **Irrigated Land**

### Soil Cover (ft)

- 2.75
- 5.75
- 4.5
- 5.5
- 5.75
- -
- 6.5
- 5.5
- 5.5
- 6.25

### Soil Observations

- Granular, sand, gravel, some silt
- Sandy, fine grained
- Clayey in trench, sand and gravel native and below
- Sandy fine grained, clayey
- Clay, moist
- Pipe Not Found, Only remnants of pipe found
- Gravel, silt, clay
- Clayey, silty, some sand
- Clayey
- Broken rock fragments

### Soil Type

- SM/SC
- SW, SM/SC
- SW, SM/SC
- CL/ML
- SM/SC
- CL/ML
- SM/SC
- CL/ML

### Ground Water

- Yes
- No
- No, dry
- Yes
- No, dry
- Yes
- No
- No, dry
- Yes
- No, dry

### Soil/Water Sulfate

- (mg/kg / mg/L)
- 146/153
- 59/-
- 39/-
- 97/34
- 14,300/-
- 20,200/13,700
- -
- 6,270/-
- 25,100/37,500
- 19,200/10,200
- 28,600/-

### Schmidt Hammer Test

- -
- 33.2
- 36.2
- 44.2
- 38
- 40.2
- -
- 41.3
- 38.3
- 35.8
- 35

### Ultrasonic Test

- -
- 72.8
- 73.3
- 71.6
- 71.1
- 70.5
- -
- 72.7
- 71.9
- 70.6
- 72.4

### Pw / Pdesign

- 0.26<br>0.41<br>0.56<br>0.63<br>0.78<br>0.64<br>-
- 0.61<br>0.88<br>0.86<br>0.77

### Other

- Intersection of 14" AC from infiltration gallery to new 8" PVS off Shell #3; Section of AC pipe obtained for testing<br>5 min. tap compared with 20 min. tap; Tap sample<br>Benign section, Clovery (Skyes Mtn Member)<br>Tap sample<br>Tap sample<br>Tap sample<br>Tap sample<br>Blow off hardware corrosion

1. Soil chemistry conductive to AC corrosion/degradation, and physical properties such as expansive clay.
2. Areas of proposed and existing highest operating pressure in the pipe.
3. Areas where pipe lies in water (shallow groundwater).
4. Other
CHAPTER 8
WELL SITING STUDY

8.1 Purpose of the Well Siting Study

The Town of Greybull has a variety of options to enhance water supplies to meet demands. Developing additional supplies from a new high yield well will always be an option that can be exercised in view of economic, technical, and political realities. The purpose of this study is to identify and rank locations for a high yield municipal water supply well in the vicinity of Greybull. The identification of groundwater development prospects can be used as a starting point for future groundwater exploration efforts by the Town of Greybull or the Big Horn Regional Water System (BHRWS).

8.2 Study Area

The study area extends eastward approximately 19 miles from the Town of Greybull to the west flank of the Bighorn Mountains, and approximately 10 miles north and south of Shell Creek Valley (Plate 8-1). This area encompasses all of T52-53N, R90-93W, and parts of T51N/T54N, R90-93W.

8.3 Study Methodology

Three fundamental aspects of a well siting study are to identify a target aquifer(s), identify hydrogeologic conditions, and to establish criteria for favorable well sites.

8.3.1 Target Aquifer

On the east side of the Big Horn Basin there are three major aquifers with the potential to provide adequate quantity and quality for municipal purposes: 1) Tensleep Sandstone, 2) Madison-Bighorn, and 3) Flathead Sandstone. Previous hydrogeologic studies by Cooley (1984), Jarvis (1986), and Doremus (1986) provide detailed descriptions of these Paleozoic aquifers along the west and southwest flank of the Bighorn Mountains. The hydrostratigraphy in the vicinity of Greybull is shown on Figure 8-1.
In the Greybull area, the Tensleep Sandstone aquifer typical has poor water quantity and quality (Doremus, 1986) and is an oil/gas reservoir. The Flathead Sandstone is relatively thin and deeply buried west of the range front. Due to the scarcity of wells completed in the Flathead Sandstone, the hydrologic properties of the Flathead Sandstone in the Greybull area are not well defined. The Tensleep and Flathead aquifers are not targets for the exploration and development of municipal water supplies in the Greybull area.

The Madison-Bighorn (M-B) aquifer, which is comprised of the Madison Limestone, Jefferson Formation, and Bighorn Dolomite, will be the primary target aquifer for this well siting study. The M-B aquifer is a proven resource for municipal water supplies as demonstrated by the Big Horn Basin communities of Greybull, Manderson, Worland, Tensleep, and Hyattville. The BHRWS will likely rely exclusively on groundwater from the M-B aquifer. A well siting study by Lidstone (2000), and subsequent groundwater resource evaluation efforts, identified the M-B aquifer as the primary target aquifer for the development of groundwater by the BHRWS in the southern part of the Big Horn Basin in the vicinity of Thermopolis. In the vicinity of Greybull, the Town’s municipal supply wells (Shell #1, Shell #2, and Shell #3) comprise the current level of groundwater development in the M-B aquifer.

8.3.2 Hydrologic Characteristics of the Madison-Bighorn Aquifer

The desire of a municipality or water service entity is to procure wells with the ability to provide 500 gpm or more (i.e., a common definition of high yield). Although the M-B aquifer has the demonstrated ability to provide artesian flow in excess of 500 gpm (e.g., Shell #2 and the Tensleep and Worland wells), more common artesian production rates are on the order of 100 to 300 gpm as demonstrated by municipal wells at Manderson, Hyattville, and two of the Greybull wells. The ability to successfully locate and complete high yield wells in the M-B aquifer is a combination of favorable hydrogeology and good fortune.

The Madison Limestone and Bighorn Dolomite consist of carbonates, namely limestone and dolomite. Carbonates have three important features related to aquifer permeability: 1) horizontal surfaces such as bedding plane styolites, 2) the tendency to
fracture, and 3) the ability to dissolve when in contact with weak acids (carbonic acid) present in rain and surface water. The intrinsic permeability (i.e., primary pore space) of limestone/dolomite is extremely low. Adequate production for most purposes depends on the presence of fractures, joints, open karst, and solution cavities capable of storing and transmitting water. The importance of horizontal fractures to provide water to a well was evident in the downhole camera survey at Shell #3.

Well siting in carbonate aquifers must focus on identifying geologic structures that produce fractures (secondary permeability) and allow groundwater circulation to enlarge fractures via dissolution. Huntoon (1993) articulated the elements of geologic structure that enhance and diminish the permeability of Paleozoic aquifers in Wyoming, and in the Big Horn Basin in particular. Ideas developed by Huntoon and University of Wyoming graduate students (Jarvis, 1986; Doremus, 1986) were used in a well siting study for the southeast Big Horn Basin (Lidstone, 2000) and will be used in this Level II study. In general, the identification of sites in the basin interior with the potential for high yields from the M-B aquifer focus on the following hydrogeologic conditions that produce enhanced secondary permeability:

- extensional fractures along the crest of fault cored anticlines;
- fractures associated with lineaments, faults, and tight folds;
- hydraulic continuity with the M-B aquifer recharge area (i.e., west flank of Big Horn Mountains);
- better water quality and groundwater circulation on the hanging walls of fault cored anticlines; and
- evidence of groundwater circulation (e.g., springs, hydraulic gradient).

More detail regarding the permeability characteristics of Paleozoic aquifers in the Big Horn Basin and approaches to water well exploration are provided in Cooley (1984), Huntoon (1993), Jarvis (1986), Doremus (1986), and Lidstone (2000).
8.3.3 **Well Siting Criteria**

Well sites with the potential for high yield and adequate water quality will be identified and ranked using the following criterion.

- Geologic structures with the potential for secondary permeability
- Hydraulic continuity with recharge areas
- Demonstrated high yield production and adequate water quality from existing wells or springs
- Proximity to existing water supply infrastructure
- Potential interference with current water users
- Land ownership and access

8.4 **Geology and Hydrogeology in the Vicinity of Greybull**

The study area comprises the elevated west flank of the Bighorn Mountains and westward along the Shell Creek Valley to the Town of Greybull. Precambrian-age crystalline basement rock is exposed in the central part of the Bighorn Mountains. Along the west flank and foothills of the range, the crystalline basement rock is covered by a thick sequence of west dipping Paleozoic-age formations (fm.) consisting of, in ascending order, the Flathead Sandstone, Gros Ventre Fm., Gallatin Fm., Bighorn Dolomite, Jefferson Fm., Madison Limestone, Amsden Fm., Tensleep Sandstone, and Goose Egg (Phosphoria) Fm. (Figure 8-1). As one proceeds west down the Shell Creek Valley to Greybull, flat-lying to gentle west dipping Mesozoic-age formations are exposed; consisting of, in ascending order, the Chugwater Fm., Gypsum Springs Fm., Sundance Fm., Morrison Fm., Cloverly Fm., Thermopolis Fm., Mowry Shale, and Frontier Fm. (Figure 8-1).

The recharge area for the M-B aquifer is the elevated highlands of the Bighorn Mountains where the Madison Limestone and Bighorn Dolomite are exposed (Plate 8-1). Water from precipitation, snow melt, and stream flow enters the M-B aquifer at these high elevations and provides the head that produces flowing artesian conditions further west in the basin. The M-B aquifer is confined west of the Madison Limestone-Amsden formation contact where the overlying Amsden Fm. serves as an upper confining layer. Groundwater in the M-B aquifer flows from east to west toward discharge points.
(springs) at the upper Madison Limestone contact and in the basin interior via interformational flow (leakage), and along the Bighorn River where the Madison Limestone is exposed at Sheep Mountain (Doremus, 1986).

Plate 8-1 illustrates the numerous regional faults, folds, and monoclines that have deformed the Paleozoic and Mesozoic stratigraphy in the study area. There is a distinctive northwest to southeast trend to the faults and folds formed by the northeast-southwest horizontal compressive forces that uplifted the Bighorn Mountains during the Laramide Orogeny (Blackstone, 1986). Typically, the asymmetric basin anticlines are the result of high angle reverse faults at depth that involve crystalline basement displacement. The faults tend to steepen as they propagate upward through the sedimentary cover (Blackstone, 1986). These structural features are critical to the identification of well sites with the potential for enhanced secondary permeability in the M-B aquifer.

Well sites should be hydraulically connected to recharge areas and be located in areas of active groundwater circulation to ensure adequate water quality and to maximize the potential for solution-enhanced permeability. Huntoon (1985, 1993) identified three types of basin margins that control the hydraulic continuity of aquifers between recharge areas and basin interiors: 1) fault severed, 2) continuous homocline, and 3) obliquely faulted. Fault severed margins occur when displacement along a major thrust fault severs the hydraulic continuity of the aquifer thereby preventing highland recharge to flow into the basin interior. Continuous homoclines provide lateral continuity of the aquifer such that recharge in the elevated highlands can flow into the basin interior. Obliquely faulted margins have faults or anticlines oriented oblique to the basin margin such that a fault/anticline can serve as a hydraulic conduit between recharge area and the basin interior.

Doremus (1986) applied these margin types to the M-B aquifer in the Greybull area and provided the following conclusions:

- The South Beaver Creek Thrust and Five Springs Thrust (Plate 8-1) sever the M-B aquifer; and
- The Shell Monocline does not sever the hydraulic continuity of the M-B aquifer and a homoclinal margin exists south of the South Beaver Creek
Thrust. Therefore, south of the South Beaver Creek Thrust, groundwater in the M-B aquifer can flow to the west-southwest, from the recharge area to the basin interior.

The homoclinal margin, and associated hydraulic continuity of the M-B aquifer, extends along the Shell Monocline southward from the South Beaver Creek Thrust to the Pebar Fault (Plate 8-1). Based on the east-west orientation of the Pebar Fault, this fault may serve as an obliquely faulted margin with the potential to convey groundwater basinward via the fault cored Cherry Anticline.

The existence of oil/gas fields and basin thrust faults provide an additional constraint on the well siting study area. As shown on Plate 8-1, numerous oil and gas fields exist north and south of Greybull. The majority of the oil/gas fields produce from Cretaceous, Permian, and Pennsylvanian age formations, but a few fields such as the Lamb, Lite Butte, and Spence Dome produce from the Madison Limestone. John Donnell and Assoc. (1982) recognized the potential for poor water quality (and oil) in the Madison Limestone in the vicinity of these oil/gas fields and recommended that sites for the Greybull #1 well not be considered west of Cherry Anticline. The thrust fault associated with the Cherry Anticline has probably severed the Madison Limestone, and may prevent hydraulic continuity and groundwater circulation to the footwall (i.e., southwest side of the thrust). Wyoming Groundwater agrees with the John Donnell and Assoc. (1982) study that well sites should not be considered southwest of the Cherry Anticline thrust.

To summarize, the well siting study area was refined based on structural elements that control hydraulic continuity in the M-B aquifer between the recharge area and basin interior in the vicinity of Greybull. The study area is defined on the east by the range front south of South Beaver Creek Thrust and north of the Pebar Fault, on the south and west by the Cherry Anticline, and on the north-northeast by Sheep Mountain and the South Beaver Creek Thrust.
8.5 Lineament Study

Lineaments are linear features that can be seen on aerial photos or high altitude satellite imagery. Lineaments may or may not have geologic or hydrogeologic significance, but are valuable features to identify in a reconnaissance-level study. Lineaments may delineate zones of structural deformation such as faults or major joint systems with the potential for secondary permeability in brittle carbonate aquifers. Morrison-Maierle (1986) used lineament mapping as the primary criterion to site the Shell #1 well.

On a regional scale, Hoppin and Jennings (1971) identified a series of east-west lineaments that cut across older Laramide structures and appear to cause segmentation of the Big Horn Mountains. Six large-scale east-west trending lineaments were identified, from south to north across the Big Horn Mountains and into the Bighorn Basin: Thermopolis, Tensleep, Florence Pass, Shell, Tongue River, and Nye-Bowler lineaments.

As stated by Hoppin and Jennings (1971), “the Shell lineament is expressed by Cenozoic fracture zone mineralization on the west and east flank of the uplift and by marked linearity and landslide topography of Shell Canyon….the extension of the Shell lineament west through Greybull is tentative and one can speculate that it continues through the hot springs at Cody and along the relatively straight Shoshone River valley.”

The expression of the Shell lineament through the Big Horn Mountains and across the Big Horn Basin is apparent in a shaded relief map of Wyoming (Edwards and Batson, 1990).

Based on the apparent presence of a large-scale lineament in the Shell Creek Valley, Wyoming Groundwater contracted Dr. Gordon Marlatt to conduct a detailed mapping study of lineaments in the well siting study area. From a well siting standpoint, lineaments represent an additional structural feature with the potential of providing enhanced secondary permeability in the M-B aquifer. The results of lineament mapping are presented on Plate 8-2 and in a text report provided in Appendix F.

The Shell Creek Lineament is an east-west shear zone that is approximately 4 miles wide and centered along the Shell Creek Valley. Shear elements within the shear zone are vertical features with left-lateral strike-slip motion. The shear zone is a very young and active feature of a presently unknown structural event. The center of the shear
zone has the greatest sense of motion, the densest occurrence of individual shear elements, and is likely to be the area of greatest hydraulic connectivity and aquifer permeability. The shear zone also has the potential to provide hydraulic connection between the recharge area and the basin interior. A high priority location for a potential high yield well is at the intersection of the center of the Shell Creek Lineament and Cherry Anticline at the northern terminus of Potato Ridge.

South of Shell Creek are two well developed shear zones. The first shear zone is approximately 4.5 miles south of Reeves Corner (Plate 8-2). This shear zone is approximately 2 miles wide and appears to have left-lateral motion. The second shear zone is approximately 11 miles south of Reeves Corner. This shear zone is quite narrow being only ½ to ¾ mile wide and has left-lateral motion.

In the future, if the Town of Greybull and/or the BHRWS wish to pursue exploratory drilling for high yield wells using the Shell Creek Lineament, in part, as a criterion for well siting, final exploratory well site locations may benefit from a more in-depth analysis of the shear elements contained within the Shell Creek Lineament.

8.6 Water and Oil Well Inventory

As shown on Plate 8-3 and Table 8-1, there are only five (5) water wells completed in the Madison-Bighorn aquifer in the vicinity of Greybull, and 4 of the 5 wells are owned by the Town of Greybull: Shell #1, Shell #2, Shell #3, and Greybull #1. The Davis #1 well has an unusually large water right of 3,000 gpm and will be discussed in detail in Section 8.8.3.

North of Shell Creek, the only wells (water or oil) completed in the Madison Limestone are associated with the Spence Dome oil field as indicated by Doremus (1986). South of Shell Creek, the nearest M-B aquifer water wells are 15 miles away, and consist of the Wild Horse #1/#2 wells that supply water to the Town of Manderson.

An important observation from the water well inventory is that in the vicinity of Greybull, approximately 12 miles north and south of Shell Creek, the M-B aquifer is an undeveloped groundwater resource. The Greybull municipal supply wells are the only wells that extract groundwater from the M-B aquifer over a 430 sq. mile area.
North and south of Greybull, there are oil wells completed in the Madison Limestone; particularly, in the Spence Dome, Lamb, and Lite Butte oil fields. Numerous other wells in the area are drilled to or through the Madison Limestone, but were subsequently plugged and abandoned (p&a) due to poor oil shows. Oil fields shown on Plate 8-1 produce oil primarily from Cretaceous, Permian (i.e., Phosphoria), and Pennsylvanian (i.e., Tensleep Sandstone) age formations. However, when the rare oil exploration well was drilled to the Madison Limestone, or deeper, some information is obtained regarding the potential water producing capabilities of the M-B aquifer. Data from well files of the Bureau of Land Management Worland field office were reviewed and pertinent information from selected oil wells (Table 8-1 and Plate 8-3) is summarized in the discussion that follows.

8.6.1 Herron Gulch #2 (aka Davis #1) – T53N, R92W, Section 27

When this well was drilled, substantial artesian flow was encountered in the Madison Limestone. The artesian flow had to be controlled with weighted mud and the well was plugged and abandoned. The well was the subject of a lawsuit between the oil company that drilled/plugged the well and a local landowner that claimed the well was improperly plugged and was responsible for subsurface groundwater discharge at his property. Conditions encountered in the Madison Limestone indicate that the M-B aquifer in the area near the Herron Gulch #2 well has the potential for high yields. This well and associated hydrogeology will be discussed in detail in Section 8.8.3.

8.6.2 McKown #1 – T53N, R92W, Section 31

The McKown #1 exploratory oil well (p&a) is located in Devils Kitchen at the north end of the Cherry Anticline (i.e., Shell Creek Dome) and penetrated 382 feet of the Madison Limestone. At 2,400 feet bgs, while tripping tubing out of the hole, the drilling mud began to flow out of the hole. Drilling was erratic from 2,420 to 2,430 feet in the Madison Limestone. No detailed information was provided on permeability or water production from the Madison Limestone.
8.6.3  1 Linderman – T52N, R92W, Section 10

The 1 Linderman exploratory oil well (p&a) is located on the crest of the Cherry Anticline approximately 1.8 miles south of State Highway 14 and 7.5 miles east of Greybull. The well penetrated the Madison Limestone and the Bighorn Dolomite. No comments are provided for the Madison Limestone. A packer test was performed in the Bighorn Dolomite and reported a pressure of 240 psi and a flow of 9.5 barrels per hour (7 gpm) of fresh water for 3 hours.

8.6.4  Govt. #1 (Zephyr Drilling) – T52, R92W, Section 5

The Govt. #1 Zephyr Drilling exploratory oil well (p&a) is located at the northern end of the Cherry Anticline approximately 700 feet south of State Highway 14 and 6.5 miles east of Greybull. The well was drilled to the Tensleep Sandstone and did not penetrate the Madison Limestone. “Fresh sweet water” and water pressure strong enough to displace the drilling mud was encountered in the Tensleep Sandstone. No problems were encountered during well plugging activities.

In 1971, the Town of Greybull filed a U.W. 5 form (P8426W – Greybull Underground No. 1) to the State Engineer’s Office (SEO) for the Govt. #1 well (Appendix F). Apparently the Town believed there was potential to use this well for municipal purposes and requested a water right at this well for 1,000 gpm. The Town never used or improved the well and the permit was cancelled by the SEO in 1972. No specific information is available to determine the basis for the Town’s desire to convert the well to municipal purposes.

8.6.5  Govt. #1 (Shell Oil) – T53N, R93W, Section 17

The Govt. #1 Shell Oil exploratory oil well (p&a) is located near the crest of the Sheep Mountain Anticline approximately 5 miles north of Greybull. From 520 to 1,422 feet bgs in the Madison Limestone there were no cutting returns using air drilling methods which indicates permeable conditions in that interval. At a drilled depth of 1,200 feet, approximately 100 feet below the bottom of the Bighorn Dolomite, the total dissolved solids concentration of a water sample from the hole was reported to be 396 mg/L. Water in the hole reportedly “fell away” during geophysical logging.
8.6.6 31-34 Wyco-Fed – T53N, R93, Section 34

The 31-34 Wyco-Fed exploratory oil well (p&a) is located at the south end of the Sheep Mountain Anticline approximately 2 miles north of Greybull. While drilling in the Madison Limestone, drilling behavior indicated fractures from 1,895 to 1,901 feet bgs and drilling fluid circulation was lost in that interval and never regained. The porosity log was off-scale from 1,896 to 1,905 feet. The measured bottom hole temperature was 76°F. Data compiled by Loy Harris (Appendix F, compiled data sheet for 53 North) indicates a depth to water of 343 feet in this well. This well indicates potential enhanced secondary permeability in the Madison Limestone.

8.7 Existing Water Supply Infrastructure

As shown on Plate 8-3, the Greybull Water Transmission Pipeline (GWTP) is located along State Highway 14 from Greybull to approximately 3 miles northeast of the community of Shell. The ability of the GWTP to accept additional flow from a high yield well will depend on the actual production from a new well and whether Greybull proceeds with the installation of pumps in the Shell #3 and Shell #1 wells. If Greybull installs pumps in Shell #3 and Shell #1, there will not be any excess capacity in the GWTP.

The BHRWS infrastructure will be located on the south side of Greybull on the west side of the Big Horn River. In all likelihood a new high yield well will require a new pipeline, and consequently, the economics of a new well will depend, in large part, on the distance to the Town of Greybull and/or the distance to a tie-in to the BHRWS infrastructure.

8.8 Water Well Prospects

As shown on Plate 8-3 and listed in Table 8-2, four (4) high yield water well prospects were identified in the vicinity of Greybull. This was a reconnaissance-level well siting effort; if the Town of Greybull or the BHRWS wish to develop an exploratory water well drilling program, a more detailed investigation of each prospect should be performed.
The general water chemistry at all four well prospects is anticipated to be suitable for municipal purposes. Water quality in an aquifer typically degrades as groundwater residence time and depth increases from highland recharge areas toward discharge points in the basin interior. However, available data from the M-B aquifer along Shell Creek Valley suggest that suitable water quality is maintained from the recharge area (e.g., Shell #3) to discharge points along the Big Horn River at Sheep Mountain (Doremus, 1986). For example, total dissolved solids concentrations in the M-B aquifer at the Shell #3 and Shell #1 wells, and springs at Sheep Mountain, are 352 mg/L, 319 mg/L, and 234 mg/L, respectively. The springs at Sheep Mountain (Plate 8-3) that discharge from the Madison Limestone are not believed to be derived from local recharge (i.e., recharge at Sheep Mountain) because thermal temperatures of the springs indicate deep artesian flow (Doremus, 1986). Water temperatures in the M-B aquifer from east to west (i.e., from Shell #3 to the springs at Sheep Mountain) trend from approximately 60 to 88°F.

The water well prospects, ranked from highest to lowest development potential, are as follows:

1. North Cherry Anticline
2. South Sheep Mountain Anticline
3. Porter Gulch
4. South Cherry Anticline

8.8.1 North Cherry Anticline Prospect

The North Cherry Anticline (NCA) prospect is the highest (#1) ranked prospect because of 1) favorable geologic structures with the potential of fracture permeability, 2) proximity to Greybull (5.3 miles), and 3) flowing artesian wellhead pressure.

The Cherry Anticline is a northwest-southeast trending asymmetric anticline with a steep southwest flank (36° average dip) and a broad northeast flank (7° average dip) (Reppe, 1981; 1986). Potato Ridge is the topographic expression of this tight asymmetric fold. Plate 8-3 contains a diagrammatic cross-section across Potato Ridge that illustrates the fold geometry and an eastward dipping thrust fault at depth responsible for the fold at ground surface.
From the cross-section, one can infer that the thrust fault completely severs the Madison Limestone. This conclusion is supported by structure contours of the Tensleep Sandstone (Rocky Mountain Map Company, 2001, SE ¼) that indicate 1,500 to 2,000 feet of vertical displacement across the thrust fault. Water well sites must attempt to penetrate the Madison Limestone and Bighorn Dolomite on the crest of the anticline in the hanging wall. Care must be taken to locate a well far enough to the east so as to not penetrate the fault plane and enter the footwall. This is also true of the South Cherry Anticline prospect.

At the NCA prospect location (T53N, R92W, Sec. 32), the nose of the anticline is well expressed at the surface however, displacement on the thrust at depth is less (or absent). Hydraulic continuity of the M-B aquifer may be better at the north end of the structure than to the south. The NCA prospect may also benefit from enhanced permeability associated with fractures in the Shell Creek Lineament shear zone.

During the course of this Level II study, Wyoming Groundwater spoke with Dr. Eric Kvale, Professor of Geology at Iowa State University (ISU) regarding geologic structures that could enhance the potential for high yield water wells. Dr. Kvale grew up in Greybull and for many years has directed the ISU geology field camp located in Shell Valley; consequently, he has an extensive knowledge of local geology. Dr. Kvale concurred that the Cherry Anticline represents the best prospect for fracture enhanced permeability in the M-B aquifer in the vicinity of the Shell Creek Valley and Greybull.

The potentiometric surface map of the Madison Limestone (Doremus, 1986) indicates that the head in the Madison may be 4,200 feet in the vicinity of the NCA prospect. Assuming a ground surface elevation of 3,900 feet, there may be 130 psi of artesian pressure at the well.

Numerous oil wells have been drilled on the Cherry Anticline to the Phosphoria-Tensleep formations, but have not produced any oil. A few wells have penetrated the Madison Limestone along the anticline, but limited data are available.

8.8.2 South Sheep Mountain Anticline Prospect

The South Sheep Mountain Anticline (SSMA) prospect is ranked #2 because of 1) favorable geologic structure with the potential of fracture permeability, 2) proximity to
Greybull (3 miles), and 3) an oil well indicating good permeability in the Madison Limestone (31-34 Wyco-Fed). Two negative aspects to the SSMA prospect is the probable lack of flowing artesian pressure at the well and probable hydraulic connection with the Big Horn River.

The SSMA prospect is located at the south end of the Sheep Mountain Anticline. Sheep Mountain is an asymmetric, northwest-southeast trending, doubly plunging anticline (Kozimko, 1977). At the SSMA location, the southern nose of the anticline is more broad and symmetrical (see cross-section on Plate 8-3) than more northern parts of the fold, with dips ranging from 7° to 17° around the southern nose of the fold.

Oil and gas wells have been drilled on the Sheep Mountain Anticline, but did not encounter oil or gas. One exploration well, 31-34 Wyco-Fed (Plate 8-3), indicated fracture permeability in the Madison Limestone.

The anticipated total drilling depth of 3,100 feet is slightly shallower than the NCA prospect, but its actual total depth will depend on final well site elevation and spud formation.

### 8.8.3 Porter Gulch Prospect

The Porter Gulch (PG) prospect is ranked #3 and is based on the Herron Gulch #2 wildcat oil well that encountered strong artesian flow from the Madison Limestone. The plugged well and prospect area are located in Porter Gulch, just north of Shell Creek, approximately 8 miles east of Greybull (Plate 8-3).

The Herron Gulch #2 well was drilled in September 1974 and has since had a very interesting history. Appendix F contains documents, listed below, that provide detailed information on Herron Gulch #2.

- Geologist’s well and activity log
- September 30, 1991, letter from Don Reichmuth that summarizes events related to the well
- June 30, 1998, letter from Crank Companies to the Town of Greybull regarding potential use of water associated with the Herron Gulch #2 (aka Davis #1)
- U.W. 5 and U.W. 6 forms on file with the SEO for the Davis #1 well
The Herron Gulch #2 well encountered strong artesian flow immediately above and in the upper 32 feet of the Madison Limestone. Weighted drilling mud (up to 10.4 lb/gal) was needed to control flow and allow the placement of four cement plugs in the borehole. Based on mud weight, the estimated pressure at the wellhead was 250 psi. Artesian flow from the well was not quantified, but was described as “strong” by the on-site geologist. A water sample (Appendix F) apparently collected from the well during flowing conditions had a total dissolved solids concentration of 466 mg/L, but high sodium and sulfate concentrations are not typical for the Madison Limestone and indicate potential contamination from drilling fluids or groundwater from overlying formations.

The apparent high yield from the well may be associated with a northwest-southeast trending fault located just northeast of the well as shown on Plate 8-1 and Plate 8-3. This fault is not expressed at the surface, but is shown on structure contour maps of the Tensleep Sandstone (Doremus, 1986; Rocky Mountain Map Company, 2001, NE/4). Given that compressional forces produced the northwest-southeast trending structures, it is reasonable to assume that this is a reverse fault, and that the fault plane dips to the southwest. If that assumption is correct, the Herron Gulch #2 well may have intersected the fault near the top of the Madison Limestone. This is speculative because other conditions may be responsible for the apparent high yield (e.g., karst, Shell Creek Lineament).

A local landowner, Mr. John Davis, contended that the Herron Gulch #2 well was improperly plugged and that water from the Madison Limestone was responsible for the high water table at his ranch on the north side of Shell Creek Valley near Porter Gulch. In 1988, a lawsuit and trial ensued between Mr. Davis and Consolidated Oil & Gas with the court decision in favor of the oil company. The former Davis Ranch property and the plugged well are currently owned by Mr. Don Reichmuth. The well name has been changed to Davis #1 and has a water right of 3,000 gpm designated for irrigation purposes (Appendix F). This water right is unusual because the volume is not from a direct measurement of artesian flow or pumping from the well (i.e., the well is plugged); instead, the water right volume is from a calculated groundwater discharge to the ranch.
property through subsurface geologic structures and formations that is facilitated by the contended improper plugging of the well.

Mr. Reichmuth has expressed the desire for the Town of Greybull and/or the Big Horn Regional Water System (BHRWS) to use the Davis #1 well as a municipal water supply under some form of mutually beneficial agreement. Use of the well would require that the well be reentered and properly completed with casing to the top of the Madison Limestone.

The risks, technical difficulties, and costs associated with recompleting the Davis #1 well are substantial. Groundwater development efforts in the M-B aquifer in the Porter Gulch area should consist of new wells offset from the Davis #1 well. In this case, Greybull/BHRWS would own outright the well(s) and water rights associated with a well/wellfield, but may have to address water rights interference issues with Mr. Reichmuth. Wellfield development in the area of the Davis #1 well may lessen to some degree the contended leakage from the Davis #1 well.

8.8.4 South Cherry Anticline Prospect

Much of the previous discussion of the NCA prospect applies to the South Cherry Anticline (SCA) prospect. The SCA prospect is located on the crest of the Cherry Anticline and at the intersection with a narrow shear zone (Plate 8-2). However, the SCA prospect is over 15 miles from Greybull, and consequently, is ranked lowest (#4) due to poor economics.

8.9 Discussion

Four water well prospects were identified with the potential to encounter secondary permeability (fractures, cavities) and associated high yield in the Madison-Bighorn aquifer. As with any groundwater development endeavor, there are no guarantees that high yield and adequate water quality will be encountered, but attention to hydrogeologic conditions will improve chances for success. As discussed in previous chapters of this report, Greybull should pursue the installation of pumps in the Shell #1 and Shell #3 wells and modifications/improvements to the GWTP, rather than the
installation of a new well(s) and pipeline, to alleviate present day and future water supply shortages.

The expense and commitment required to develop additional groundwater supplies, using this well siting study as a guide, should be taken on by a larger water supply entity such as the Big Horn Regional Water System. To date, the BHRWS has focused its water supply procurement efforts on the Worland wells and at the south end of the regional water supply system, but future water supply development efforts may shift to the north end of the system in the vicinity of Greybull.
TABLES AND FIGURES
Table 8-1: Inventory of Wells Completed in the Madison-Bighorn Aquifer in the Vicinity of Greybull, Wyoming

Greybull Wells Rehabilitation, Level II, Study

Vicinity of Greybull, Wyoming

<table>
<thead>
<tr>
<th>Permit No.</th>
<th>Location</th>
<th>Permitted Use</th>
<th>Permit Owner</th>
<th>Permittee Name</th>
<th>Water Depth (ft)</th>
<th>Pressure (+)</th>
<th>Wellhead Pressure (+)</th>
<th>Permit No.</th>
<th>Township, Range, Sec.</th>
<th>Municipality</th>
<th>Owner Name</th>
<th>Yield, gpm</th>
<th>Comments</th>
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<tbody>
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<td>P75584W</td>
<td>53, 91, 35</td>
<td>Mun, Mis, Sto</td>
<td>Town of Greybull</td>
<td>Shell Valley #1</td>
<td>300</td>
<td>+ 307</td>
<td>2,440</td>
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<td>P75583W</td>
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<td>Mun, Mis, Sto</td>
<td>Town of Greybull</td>
<td>Shell Valley #2</td>
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<td>P102870W</td>
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<td>Mun, Mis</td>
<td>Town of Greybull</td>
<td>Shell #3</td>
<td>300</td>
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<td>Cancelled</td>
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<td>Irr</td>
<td>Town of Greybull</td>
<td>Davis #1</td>
<td>3,000*</td>
<td>+ 577</td>
<td>2,922</td>
<td>*See Chapter 8 text</td>
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Oil and Gas Wells

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<th>Permit Owner</th>
<th>Permittee Name</th>
<th>Water Depth (ft)</th>
<th>Pressure (+)</th>
<th>Wellhead Pressure (+)</th>
<th>Permit No.</th>
<th>Township, Range, Sec.</th>
<th>Municipality</th>
<th>Owner Name</th>
<th>Yield, gpm</th>
<th>Comments</th>
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</tbody>
</table>

Notes: Mm = Madison Limestone    
bgs = below ground surface    
Mun = Municipal    
Mis = Miscellaneous    
Sto = Stock    
Irr = Irrigation    
Ind = Industrial

South of the Study Area (From North to South)

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<th>Permit No.</th>
<th>Location</th>
<th>Ind</th>
<th>Permit Owner</th>
<th>Permittee Name</th>
<th>Water Depth (ft)</th>
<th>Pressure (+)</th>
<th>Wellhead Pressure (+)</th>
<th>Permit No.</th>
<th>Township, Range, Sec.</th>
<th>Municipality</th>
<th>Owner Name</th>
<th>Yield, gpm</th>
<th>Comments</th>
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<td>51, 92, 35</td>
<td>Ind</td>
<td>Atlantic Oil &amp; Gas</td>
<td>Lite Butte Federal #3</td>
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<td>N.A.</td>
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<td>P1039W</td>
<td>50, 90, 34</td>
<td>Dom, Sto, Irr</td>
<td>Chester Mercer</td>
<td>Mercer #1</td>
<td>1,500</td>
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<td>3,995</td>
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<td>Worland #1 (Husky Well)</td>
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<td>Fishery</td>
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<td>Freddy #1</td>
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- See Chapter 8 text
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<tr>
<th>Rank</th>
<th>Prospect Name</th>
<th>Location</th>
<th>Land Ownership</th>
<th>Estimated Depth to Top of Madison Ls. ft. bgs</th>
<th>Estimated Depth to Bottom of Bighorn Dol. ft. bgs</th>
<th>Estimated Head or Depth To Water (-) ft. amsl</th>
<th>Estimated Pressure (+) ft./psi</th>
<th>Distance to Greybull miles</th>
<th>Hydrogeologic Conditions</th>
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<td>1</td>
<td>North Cherry</td>
<td>T53N, R92W</td>
<td>Private</td>
<td>2,160</td>
<td>3,390</td>
<td>4,200</td>
<td>300/130</td>
<td>5.3</td>
<td>Intersection of anticline and lineament</td>
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<td>Anticline</td>
<td>Sec. 32</td>
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<td>Spud in Clovery Fm.; grd elev. = 3,900 ft.</td>
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<td>2</td>
<td>South Sheep</td>
<td>T53N, R93W</td>
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<td>4,000</td>
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<td>3.0</td>
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<td>Mountain</td>
<td>Sec. 34/35</td>
<td>BLM</td>
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<td>Spud in Sundance Fm.; grd elev. = 4,000 ft.</td>
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<td>4,120</td>
<td>4,645</td>
<td>575/250</td>
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<td>Near productive (water) wildcat oil hole</td>
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<td>Sec. 27</td>
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<td>Possible intersection with fault at depth</td>
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<td>Spud in Mowry Shale; grd elev. = 4,070 ft.</td>
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<td>?/?</td>
<td>15.6</td>
<td>Intersection of anticline and lineament</td>
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<td>Anticline</td>
<td>Sec. 35</td>
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<td>Spud in Chugwater Fm.; grd elev. = 5,300 ft.</td>
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<tr>
<td>CRETACEOUS</td>
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<td></td>
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<td>MOWRY SHALE 585'</td>
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<td>THERMOPOLIS SHALE 335'</td>
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<td>CLOVERLY FM. 330'</td>
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<td>JURASSIC</td>
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<td>MORRISON FM. 320'</td>
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<td>SUNDANCE FM. 330'</td>
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<td></td>
<td>GYPSUM SPRINGS FM. 200'</td>
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<td>TRIASSIC</td>
<td></td>
<td>CHUGWATER FM. 660'</td>
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<tr>
<td>PERM/</td>
<td>GOOSE EGG (PHOSPHORIA) FM. 225'</td>
<td>TENSLEEP FORMATIONS (AS SHOWN) PRIMARY FINE-GRAINED CLASTIC LITHOLOGY WITH POOR WATER QUALITY AND PRODUCTION CHARACTERISTIC. LEAKY CONFINING LAYERS (DOREMUS, 1986). NOT SUITABLE FOR MUNICIPAL PURPOSES.</td>
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<tr>
<td>TRIASSIC</td>
<td>PENNSYLVANIAN</td>
<td>TENSLEEP SANDSTONE 100'</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>PENNSYLVANIAN/</td>
<td>AMSDEN FM. 160'</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>MISSISSIPPIAN</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>MISSISSIPPIAN</td>
<td>MADISON LIMESTONE 750'</td>
<td>TENSLEEP AQUIFER SANDSTONE, YIELDS GENERALLY &lt;300 GPM, WATER QUALITY IS POOR IN GREYBULL AREA.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>DEVONIAN</td>
<td>JEFFERSON FM. 100'</td>
<td>SILTSTONE AND CARBONATE. LEAKY CONFINING LAYER (DOREMUS, 1986).</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>ORDOVICIAN</td>
<td>BIGHORN DOLOMITE 380'</td>
<td>MADISON - BIGHORN AQUIFER LIMESTONE/DOLOMITE, YIELDS ARE VARIABLE. FRACTURED CARBONATE CAN PRODUCE YIELDS &gt;1,000 GPM, WATER QUALITY IS EXCELLENT, DEPENDABLE MUNICIPAL SUPPLY.</td>
<td></td>
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</tr>
<tr>
<td>CAMBRIAN</td>
<td>GALLATIN FM. 500'</td>
<td>GLAUCONITE SHALE AND CARBONATE. LEAKY CONFINING LAYERS (DOREMUS, 1986).</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>GROS VENTRE FM. 420'</td>
<td>FLATHEAD AQUIFER SANDSTONE, THIN TO ABSENT, DEEPLY BURIED, NOT MUCH KNOWN ABOUT AQUIFER IN GREYBULL AREA.</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>FLATHEAD SANDSTONE 10 TO 200'</td>
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**FIGURE 8-1**
Hydrostratigraphy in the Vicinity of Greybull, Wyoming
Greybull Wells Rehabilitation, Level II, Study

Wyoming Groundwater, LLC
CHAPTER 9
CONCEPTUAL DESIGNS AND COST ESTIMATES

9.1 Introduction

This chapter provides conceptual designs and cost estimates for projects that can provide Greybull a water supply and transmission system that will meet present day and 2030 year planning horizon water demands within the operational capacity of the Greybull Water Transmission Pipeline (GWTP). Information presented in Chapters 3 – 7 indicate that the installation of pumps in the Shell #3 and Shell #1 wells can satisfy current and future demands, and that modification of existing valves will allow the GWTP to convey the required water (i.e., 1,700 gpm) under reasonable pressure conditions in the pipeline. Although a new well in the Madison-Bighorn aquifer is not recommended for development by the Town, a conceptual design and cost estimate for the highest ranked prospect is provided.

9.2 Draft Report Alternatives

Discussions with system operators indicated the desire to present preliminary designs and cost estimates for a variety of improvements to the GWTP. Five GWTP improvement alternatives were presented in the October 2005 Draft Report (Appendix E, Draft Report Chapters 7 and 8) and are summarized to provide the reader a brief overview of past conceptual design considerations.

1) New Greybull Water Transmission Pipeline
2) New Transmission Pipeline to Shell Valley Users
3) Modify GWTP for High Pressure Operation
4) Pressure Booster Stations
5) Adjust/Modify Existing Valves

Alternatives 1 and 2 involve the construction of a new pipeline from Greybull to the community of Shell. Estimated construction costs (2005 $) was on the order of $8,000,000 to $10,500,000 (Appendix G), and are probably substantially higher due to increases in construction costs. Based on the evaluation of the GWTP, the Level II study
team believes that construction of 16 miles of new pipeline is not necessary and is probably not feasible due to cost and politics.

Alternative 3 involves a simplification of the valve arrangement on the GWTP that would result in much higher operating pressure in the pipeline and at service taps. The hydraulic modeling and pipeline material investigation discussed in Chapter 7 indicates that operating the AC pipeline at significantly higher pressures is not appropriate. Technical and political problems associated with higher pressures at customer service taps is also a problem. Consequently, Alternative 3 is not recommended.

Alternative 4 involves the installation of pressure booster stations. The required water flow rates can be delivered with the present pipeline system without sacrifice to delivery pressure by constructing pressure booster stations. These stations could be installed at the downstream side of each storage tank at Shell #3 and Shell #1/#2 or with a single station just west of the community of Shell. Because of the added operational complexity, the booster station alternative is not recommended. Estimated construction costs (2005 $) is estimated at $1,000,000 (Appendix G).

Alternative 5, adjust/modify existing valves (in conjunction with installation of pumping systems in Shell #3 and Shell #1, is technically feasible and is a relatively low cost option for Greybull to develop additional water supplies. The remainder of this chapter is devoted to a presentation of a conceptual design for this alternative.

9.3 Pumping Systems in Shell #1 and Shell #3

In both Shell #1 and Shell #3, pumps would be set at approximately 400 feet and pumping water levels at 450 gpm would be on the order of 300 feet (Figure 9-1). In Shell #1, an 8-inch diameter motor and 60 HP pump would be required. In Shell #3, an 8-inch diameter motor and 75 HP pump would be required. Both wells could be pumped during high demand periods and allowed to flow artesian during low demand periods. Discharge from the pump would be conveyed out of the well and into piping that supplies water to the adjacent storage tanks. Artesian flow would be conveyed from the well in a manner similar to the present-day piping configuration. An air-line set above the pump bowls
would be used to monitor water levels during pumping. Water level data can be integrated into the existing telemetry system.

As shown on Table 9-1, the estimated cost to install pumping systems in Shell #1 and Shell #3 is about $510,000.

9.4 Modifications and Improvements to the GWTP

This option involves modifications to the existing pressure control valves in the system to achieve the desired water supply objectives as described in previous chapters. Water supply objectives can be achieved with relatively minor modifications to the GWTP as described below. Figure 9-2a and Figure 9-2b illustrate conceptual design modifications along the GWTP as described below.

- Retrofit the existing Roll-Seal valve at the Dog Pound to control line discharge into the 1 MG tank. The valve would modulate to maintain a predetermined water level in the tank. This would keep the tank from overflowing and spilling.

- Operate the Lucas, Whaley, and Shell Valves as pressure reducing valves only, to maximize discharge. The existing pressure sustaining pilot piping set points should be set below the expected lowest hydraulic grade line to act as a safety feature against very low pressure during conditions like line leaks.

- Refurbish all Roll-Seal Valves at Dog Pound, Lucas, and Whaley Cla-Val at Shell by installing new diaphragms, seals, and miscellaneous parts such as strainers.

- Reduce the size of the Two-Bit Roll Seal and provide flow control functionality. Specifically, this would be a Combination Rate of Flow Control Valve with pressure reducing and sustaining capability. The operator will be able to “dial in” an amount of water from the Shell #3 well. Presently, adjustments to the amount of water coming from Shell #3 are difficult to achieve. Balancing supplies from Shell #3 and Shell #1/#2 makes the best use of the system hydraulic energy. In effect, better balancing allows for the same flow at less energy loss (hydraulic head loss).
preservation of energy is a benefit to the system in that flow can be maximized to Town with less impact on Shell Valley users.

- Install pressure relief systems at Dog Pound, Lucas, Whaley, and Shell, as additional protection against damaging line pressures or transients. Small pressure relief valves would be tapped (saddled) into the main line on the upstream side of the main line Roll Seal valve. Discharge from the small relief valve would be routed to the ground surface.

- Install small pressure control valves in the by-pass lines at the exiting valves. This will protect against transient pressure problems during service of the main line valves. Main valve service should occur about every 5 years.

- Make improvements to the telemetry system to reduce operational difficulty and increase system reliability. More reliable communications would improve operator warnings of problems and improve operator confidence in the telemetry system. Improvements to the system could also be made to change the way pressure at various locations in the system is monitored.

As shown in Table 9-2, the cost to perform the modifications listed above is about $220,000.

9.5 Project Integration and Cost Estimate

For simplicity, the installation of pumping systems in Shell #3 and Shell #1 and modifications/improvements to the GWTP have been discussed separately. Both tasks, however, have to occur for Greybull to obtain sufficient water supplies for present and future water demands. The cost for the total project to install pumping systems in Shell #3 and Shell #1, make improvements on the GWTP, and provide for project final design and contingencies is about $730,000.

If the Town does not wish to proceed immediately with the installation of pumping systems in the wells, water system operators should consider performing the GWTP improvements listed in Section 9.4 to enhance pipeline safety, operator efficiency,
system monitoring, and water saving capabilities. In this case, the cost estimate provided in Table 9-2 would apply.

9.6 New Well at North Cherry Anticline Prospect

The North Cherry Anticline Prospect was considered to be the highest ranked prospect for groundwater development in the Madison-Bighorn aquifer in the vicinity of Greybull. This alternative assumes that production from the well would allow the Town to meet the planning horizon water demands without needing to enhance source production at the existing Shell wells or connect to the BHRWS. It is easy to assume that a well will produce 1,000 gpm, but it is another to actually get it. With respect to enhancing Greybull’s water supply, this alternative is speculative, whereas the alternative involving pumping systems and GWTP modifications are based on a demonstrated ability of Shell #1 and Shell #3 to produce additional water.

A critical design assumption is that the well will yield 1,000 gpm with sufficient remaining hydraulic energy to pipe the water to the 1.0 MG tank via a water transmission pipeline dedicated to water transmission (i.e., without service connections). A 14-inch diameter PVC pipeline would be adequate. Wellhead completion design would look very similar to the existing Shell #1/#2 and Shell #3 wells, including a chlorination system. However, the North Cherry Anticline alternative would not require a water storage tank near the wellhead, as there are at the Shell wells.

Conceptual designs for the North Cherry Anticline well and two potential locations/pipeline alignments are shown on Figure 9-3 and Figure 9-4, respectively. Pipelines from these alternative locations are routed as short as possible to the existing alignment of the GWTP. Depending on the actual location of the existing line, a new line may or may not fit in the GWTP pipeline easement. Also, the current easements probably do not explicitly allow for multiple pipelines. As such, additional right-of-way may be required, but obtaining more right-of-way along the existing corridor should be the easiest solution.

As shown on Table 9-3, the North Cherry Anticline Prospect option is estimated to cost about $5,100,000.
9.7 Environmental Report

Depending on the project, an Environmental Report (ER) that complies with NEPA is required by certain funding agencies (e.g., State Revolving Fund, SRF). No components of this Level II study required an ER. In the fall of 2006, the Town did not submit an application for WWDC Level III funding for water supply projects described in this chapter. In anticipation of the possibility that, in the future, Greybull may apply for a loan from SRF, the initial step of the ER process (i.e., obtain responses from state and federal agencies) was performed for the proposed projects presented in this chapter and in the Draft Report. Responses from state and federal agencies including Wyoming State Historic Preservation Office (SHPO), Corps of Engineers, WDEQ, Wyoming Game and Fish, and the US Fish and Wildlife Service are presented in the project notebook.

An ER will not be needed for the installation of pumping systems and modifications/improvements to the GWTP; however, an ER will be needed if the Town or the BHRWS decides to drill a new municipal water supply well and pipeline at locations identified in Figure 9-4. Based on agency responses, an ER for a well and pipeline project would, at a minimum, need to address the following: 1) Cultural Resource Survey (SHPO), 2) potential impact to Shell Creek as a result of aquifer development (WY Game and Fish), and 3) impacts to threatened and endangered species, migratory birds, and wetlands/riparian areas (US Fish and Wildlife Service).

9.8 Discussion

In this Level II study, a variety of alternatives were considered to replace or modify the GWTP. The modification of existing valves and operation of the GWTP is a technically feasible and economical approach for Greybull to obtain additional water supplies via pumping of existing wells.

Benefits to the Greybull water system include:

- Installation of pumps in Shell #1 and Shell #3 can alleviate present day water shortages and meet water demands for planning horizon 2030.
- Modification of existing valves and system telemetry can:
  - eliminate overflow spillage at 1 MG storage tank;
- put less stress on the wells and allow the wells/aquifer to recover seasonally;
- eliminate need for operators to seasonally adjust valves;
- allow greater flow rates with acceptable operating pressures in the pipeline;
- improve system monitoring, data collection, record keeping, and efficiency; and
- reduce the vulnerability of the pipeline to excessive pressure and thereby enhance pipeline longevity.

- The total cost to install pumps and modify existing valves and telemetry is about $730,000 which is substantially less expensive than other alternatives to procure additional water supplies.
- Modest pressure increases/decreases will occur at customer point of use as a result of modifications to existing valves and system operation.
TABLES AND FIGURES
Table 9-1: Cost Estimate for Pumping Systems in Shell #3 and Shell #1, Greybull Wells Rehabilitation, Level II, Study

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Quantity</th>
<th>Cost/Unit</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Mobilization and Bonds (5% of Items 2-4)</td>
<td>LS</td>
<td>5%</td>
<td>$17,875</td>
<td>$17,875</td>
</tr>
<tr>
<td>2 Pumping System - Shell #1</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a Pumping equipment and installation</td>
<td>LS</td>
<td>1</td>
<td>$50,000</td>
<td>$50,000</td>
</tr>
<tr>
<td>b Provide 3-phase power</td>
<td>LS</td>
<td>1</td>
<td>$25,000</td>
<td>$25,000</td>
</tr>
<tr>
<td>c Electrical connection</td>
<td>LS</td>
<td>1</td>
<td>$20,000</td>
<td>$20,000</td>
</tr>
<tr>
<td>d Telemetry improvements</td>
<td>LS</td>
<td>1</td>
<td>$30,000</td>
<td>$30,000</td>
</tr>
<tr>
<td>e Wellhead piping and misc. improvements</td>
<td>LS</td>
<td>1</td>
<td>$15,000</td>
<td>$15,000</td>
</tr>
<tr>
<td>3 Pumping System - Shell #3</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>a Pumping equipment and installation</td>
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<td>1</td>
<td>$60,000</td>
<td>$60,000</td>
</tr>
<tr>
<td>b Provide 3-phase power</td>
<td>LS</td>
<td>1</td>
<td>$60,000</td>
<td>$60,000</td>
</tr>
<tr>
<td>c Electrical connection</td>
<td>LS</td>
<td>1</td>
<td>$20,000</td>
<td>$20,000</td>
</tr>
<tr>
<td>d Telemetry improvements</td>
<td>LS</td>
<td>1</td>
<td>$30,000</td>
<td>$30,000</td>
</tr>
<tr>
<td>e Wellhead piping and misc. improvements</td>
<td>LS</td>
<td>1</td>
<td>$15,000</td>
<td>$15,000</td>
</tr>
<tr>
<td>4 Unlisted Items (10% of Items 2-3)</td>
<td>LS</td>
<td>10%</td>
<td></td>
<td>$32,500</td>
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</table>

A Construction Cost Subtotal                                      $375,375
B Engineering Costs (10% of A)                                     10% $37,538
C Subtotal (A+B)                                                    $412,913
D Contingency (15% of C)                                            15% $61,937
E CONSTRUCTION COST TOTAL (C+D)                                     $474,849

F Prepare Final Design and Specs (5% of E)                          5% $23,742
G Permitting and Mitigation                                         1% $4,748
H Legal Fees                                                        0% $0
I Acquisition of Access and ROW                                     0% $0

PROJECT TOTAL COST                                                  $503,340
ROUNDED TOTAL COST                                                  $510,000
Table 9-2: Cost Estimate for GWTP Valve and Telemetry System Improvements. Greybull Wells Rehabilitation, Level II, St

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Quantity</th>
<th>Cost/Unit</th>
<th>Total Cost</th>
</tr>
</thead>
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<td>Mobilization and Bonds (10% of Items 2-4)</td>
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<td>10%</td>
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<tr>
<td>Valve Modifications</td>
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<td></td>
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<tr>
<td>a 3/4&quot; Copper Pressure Sensing Line (Tank to Dog Pound Vault)</td>
<td>LS</td>
<td>1</td>
<td>$2,500</td>
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</tr>
<tr>
<td>b Dog Pound (Solinoid Valve for Modulation)</td>
<td>LS</td>
<td>1</td>
<td>$5,000</td>
<td>$5,000</td>
</tr>
<tr>
<td>c Pressure Relief Retrofit (@ Dog Pound, Lucas, Whaley, Shell Vaults)</td>
<td>EA</td>
<td>4</td>
<td>$1,500</td>
<td>$6,000</td>
</tr>
<tr>
<td>d By-pass piping and small valves, Lucas, Whaley, Shell and Two Bit</td>
<td>EA</td>
<td>4</td>
<td>$1,500</td>
<td>$6,000</td>
</tr>
<tr>
<td>e Roll Seal and Cla-val repair kits</td>
<td>EA</td>
<td>5</td>
<td>$500</td>
<td>$2,500</td>
</tr>
<tr>
<td>f Change out two-bit (smaller and with flow control)</td>
<td>LS</td>
<td>1</td>
<td>$5,000</td>
<td>$5,000</td>
</tr>
<tr>
<td>g Valve Installation/Refurbish (Items b.c.d.e general Contractor)</td>
<td>LS</td>
<td>1</td>
<td>$30,000</td>
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<tr>
<td>h Start-Up/Inspection (John Tedder)</td>
<td>DAY</td>
<td>5</td>
<td>$1,200</td>
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<tr>
<td>i Electrical Work (subcontractor on controller and telem mods)</td>
<td>LS</td>
<td>1</td>
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</tr>
<tr>
<td>Telemetry - modest upgrades</td>
<td></td>
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</tr>
<tr>
<td>a Telemetry Improvements (New Host and Software)</td>
<td>LS</td>
<td>1</td>
<td>$10,000</td>
<td>$10,000</td>
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<tr>
<td>b Upgrade Controller Units (Wells 1&amp;2 &amp; No.3)</td>
<td>EA</td>
<td>3</td>
<td>$3,000</td>
<td>$9,000</td>
</tr>
<tr>
<td>c Odessa Tower MDS Repeater System</td>
<td>LS</td>
<td>1</td>
<td>$5,000</td>
<td>$5,000</td>
</tr>
<tr>
<td>d Tower Upgrade @ Town Hall</td>
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<td>Unlisted Items (10% of Items 2-3)</td>
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</tbody>
</table>

A Construction Cost Subtotal | | | $124,630 |

B Engineering Costs (10% of A) | | | $12,463 |

C Subtotal (A+B) | | 10% | $137,093 |

D Contingency (% of C) | | 15% | $20,564 |

E CONSTRUCTION COST TOTAL (C+D) | | | $157,657 |

F Prepare Final Design and Specs (% of E) (Will require final model and WDEQ) | | 25% | $39,414 |

G Permitting and Mitigation | | 0% | $0 |

H Legal Fees | | 0% | $0 |

I Acquisition of Access and ROW | | 10% | $15,766 |

PROJECT TOTAL COST | | | $212,837 |

ROUNDED TOTAL COST | | | $220,000 |
<table>
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<tr>
<td>G</td>
<td></td>
<td></td>
<td></td>
<td>$50,000</td>
</tr>
<tr>
<td>H</td>
<td></td>
<td></td>
<td></td>
<td>$10,000</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td></td>
<td></td>
<td>$50,000</td>
</tr>
</tbody>
</table>

PROJECT TOTAL COST $5,138,048
ROUNDED TOTAL COST $5,140,000

Table 9-3: Cost Estimate for North Cherry Anticline Well. Greybull Wells Rehabilitation, Level II, Study
CONCEPTUAL DESIGN
MODIFICATIONS AND IMPROVEMENTS TO THE GREYBULL WATER TRANSMISSION PIPELINE

FIGURE 9-2A

- Refurbish existing hydraulic valves
- Install pressure relief and bypass piping
- Install bypass PRV/PSV for main valve service
- Operate main line valves as PRVs with PSV backup

Retrofit existing valve to modulate and provide constant tank level.

Greybull Water Transmission Pipeline (GWTP)

Greybull #1 Well

Whaley PRV/PSV

Lucas PSV

Greybull 1.0 MG Tank

Dog Pound PRV/PSV

Greybull #1 Well

Smith Valve

Two Bit PRV/PSV

Open existing gate valve

Shell #3 Well and 0.10 MG tank

Abandoned Infiltration Gallery (Shell Creek)

Shell 0.35 MG Tank

Shell #2 Well

Shell #1 Well

Make modest telemetry improvements to improve system reliability.

Replace existing 8-inch valve with 4-inch valve with flow control functionality and PR/PS.

Shell PRV
FIGURE 9-2B
CONCEPTUAL DESIGN
PRESSURE RELIEF AND
PRV/PSV BY-PASS

GREYBULL WELLS REHABILITATION, LEVEL II STUDY
WYOMING WATER DEVELOPMENT COMMISSION

DRAWING SCANNED FROM CRANK COMPANIES, INCORPORATED,
(AS CONSTRUCTED/RECORD DRAWING, 1998)
FIGURE 9-3
Conceptual Design
North Cherry Anticline
Well Construction

Greybull Wells Rehabilitation, Level II, Study

WYOMING
GROUNDWATER, LLC
CHAPTER 10
FINANCING

10.1 Introduction

This chapter describes project financing resources and project financing for projects described in Chapter 9.

- Shell #3 and Shell #1 pumping systems
- Modifications and improvements to the GWTP
- New well at the North Cherry Anticline Prospect

10.2 Draft Report Alternative Financing

The October 2005 Draft Report provided a comparison of water supply enhancement project financing for alternatives developed in this Level II study and alternatives developed by Engineering Associates (2003). The comparison table presented in the Draft Report is provided in Appendix G and shows that adjusting the valves on the GWTP was the most economical option to obtain additional water supplies. A comparison of monthly water rate increases for the various supply enhancement options indicates that this preliminary conclusion is still valid.

10.3 Financing Resources

Several state and federal funding agency programs are available to assist communities with water system improvements projects. As a general rule, it takes 1 to 2 years to secure funding from these sources.

10.3.1 Wyoming Water Development Commission (WWDC)

The WWDC provides funding for the construction of various water supply projects, including water source development, water transmission, and water storage. Projects may be new or rehabilitation of existing facilities. Items related to water distribution and water treatment are not eligible for WWDC funding; however, WWDC does fund chlorination facilities. At the present time, eligible projects receive a 67% grant and 33% loan arrangement. The loan portion of the financing, if needed, does not
have to originate from the WWDC, and often times does not because more competitive loan rates can be found with other programs. However, if a loan is needed from the WWDC, the present loan rate is 4.0% for a 30 year (negotiable) term.

10.3.2 County Capital Facilities Tax

Big Horn County does not have a capital facilities tax in place with which to use as revenue for capital projects. Capital facilities taxation is a common source of water project funding in many counties.

10.3.3 USDA Rural Development – Rural Utilities Service

The Rural Utility Service (RUS) administers a grant and loan program that assists communities with water and wastewater infrastructure. The RUS program often jointly participates with state agencies on water and wastewater infrastructure.

The eligibility of a community to receive grant funding depends on two criteria. The first criterion is that the annual indebtedness on the project must exceed 1% percent of the median household income. However, this is typically not the controlling criterion. The second criterion is that the grant funding can not result in a monthly user fee that is less than the average for the area and type of community. Based on discussions with RUS officials, the minimum monthly tap fee for Greybull customers would be in the range of $30 to $35 per month. Program loans are very competitive, with interest rates currently at 4.5% for a 30 year term.

Discussions in September 2005 with RUS staff indicate that grant money from the federal program has gotten difficult to acquire. Current planning assumptions are for RUS to participate on eligible projects at the 20% grant and 80% loan level.

Projects undergo more environmental scrutiny under this program, requiring environmental assessments in some instances. The post-construction monitoring is more onerous than other funding programs. Given the low grant percentage, semi-competitive interest rate, and administrative requirements, the RUS program probably is not going to be the primary choice for a project grant/loan.
10.3.4 Wyoming State Land and Investment Board (WSLIB)

WSLIB grants and loans may be available for projects not eligible for funding through the WWDC program, including water distribution system improvements and water treatments projects. The WSLIB program also funds source development, transmission, and storage projects. At the present time, the most favorable scenario is for a maximum 75% project grant from the combined resources of the WWDC and WSLIB. At the present time there is a great deal of competition for the grant money, so obtaining this most desired arrangement may take time, assuming that the Town’s needs rank high relative to other communities.

10.3.5 State Revolving Fund (SRF)

The Wyoming Department of Environmental Quality (WDEQ) administers the EPA-financed revolving loan fund program in Wyoming. SRF fund provide loans (no grants) for all types of water development. Currently the SRF provides 2.5% loan financing with a 20-year term. The proposed project must be prioritized according to the program’s priority system. Given the low interest rate, a SRF loan for the non-grant portion of a project is attractive.

Depending on the project, eligibility for SRF funds may require an Environmental Report (ER). Of the projects described in this chapter, the North Cherry Anticline Prospect would require an ER (see Section 9.7).

10.4 Financing Assumptions

This section presents a set of assumed project financing conditions to be considered by the Town. The basic financing assumptions are summarized as follows:

- WWDC/WSLIB would participate at a favorable level on grants (75% maximum) for water source (including chlorination facilities), transmission, and storage projects;
- WSLIB/RUS would participate at a favorable level on grants (75% maximum) related to projects whose primary elements were water treatment items;
- Greybull could not contribute cash from reserves or other sources;
- If the RUS program were used, an RUS loan (an RUS loan is required when RUS grants are made) would have the same net financing affect as if an SRF loan were acquired;
- SRF loan program would be used for loan financing;
- Current debt service would continue at a rate of about $190,000 per year. Current debt service of the Town has a variable payout schedule and will continue until about 2025;
- A reserve building account is needed and will be funded via water rates. The amount of this annual reserve amount has not been formalized by the Town; and
- Annual operations and maintenance expenses are presented in Table 10-1. This approximation was provided in consultation with Town staff, but does not represent a documented value.

In the fall of 2006, the Greybull did not submit an application for WWDC Level III funding for water supply projects described in this chapter. When and if Greybull decides to apply for Level III funding, the cost estimates and financing assumptions for the project(s) should be updated to reflect the most current costs and grant/loan terms of the participating agency.

10.5 Financing Summary

Table 10-2 summarizes the results of applying these financing assumptions to the projects described in Chapter 9. The economic comparison of these projects boils down to the increase in the average monthly service charge that the Town would pass on to the consumer to service the debt. Installing pumps in Shell #1/Shell #3 and making the recommended modifications and improvements to the GWTP may result in an increase in monthly service charge of approximately $1.03 which is substantially less expensive than the estimated increase of $7.29 from a new well at the North Cherry Anticline Prospect.
<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Amount</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Salaries and benefits</td>
<td>$50,000</td>
<td>Full-time Operator and a backup</td>
</tr>
<tr>
<td>2</td>
<td>Parts and repairs</td>
<td>$20,000</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Pumping - electrical only</td>
<td>$0</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Electrical - service charge</td>
<td>$0</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>insurance</td>
<td>$500</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>chemicals, testing</td>
<td>$4,000</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>office supplies, printing, misc</td>
<td>$1,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>TOTAL</strong></td>
<td><strong>$75,500</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>USE</strong></td>
<td><strong>$76,000</strong></td>
<td></td>
</tr>
</tbody>
</table>
Table 10-2: Project Financing Summary for Greybull Water Supply Improvements, Greybull Wells Rehabilitation, Level II, Study

<table>
<thead>
<tr>
<th>GRANTS AND LOANS</th>
<th>Shell #3 and Shell #1 Pumping Systems</th>
<th>GWTP Improvements</th>
<th>New Well at North Cherry Anticline</th>
<th>Greybull Water System Base Charge*</th>
</tr>
</thead>
<tbody>
<tr>
<td>A ROUNDED PROJECT COST ESTIMATE (Tables 9-1, 9-2, and 9-3)</td>
<td>$510,000</td>
<td>$220,000</td>
<td>$5,140,000</td>
<td>$</td>
</tr>
<tr>
<td>B GRANTS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Total of WWDC/WSLIB/RUS Grant Eligible Items (Tables 9-1, 9-2, and 9-3)</td>
<td>$510,000</td>
<td>$220,000</td>
<td>$5,140,000</td>
<td>$</td>
</tr>
<tr>
<td>2 WWDC or WSLIB Grant (67% of B1)</td>
<td>$341,700</td>
<td>$147,400</td>
<td>$3,443,800</td>
<td>$</td>
</tr>
<tr>
<td>3 WSLIB or RUS Grant (Brings Grants total to 75% of A)</td>
<td>$40,800</td>
<td>$17,600</td>
<td>$411,200</td>
<td>$</td>
</tr>
<tr>
<td>4 Grant Total (B2+B3)</td>
<td>$382,500</td>
<td>$165,000</td>
<td>$3,855,000</td>
<td>$</td>
</tr>
<tr>
<td>C SPONSOR (Cash)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 From County Capital Facilities Tax (% of A)</td>
<td>0%</td>
<td>$</td>
<td>$</td>
<td>$</td>
</tr>
<tr>
<td>D LOANS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SRF Loan Amount (A-B4-C1)</td>
<td>$127,500</td>
<td>$55,000</td>
<td>$1,285,000</td>
<td>$</td>
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USER COSTS

<table>
<thead>
<tr>
<th>ANNUAL LOAN PAYMENTS</th>
<th>Shell #3 and Shell #1 Pumping Systems</th>
<th>GWTP Improvements</th>
<th>New Well at North Cherry Anticline</th>
<th>Greybull Water System Base Charge*</th>
</tr>
</thead>
<tbody>
<tr>
<td>A SRF Loan Interest</td>
<td>$8,179</td>
<td>$3,528</td>
<td>$82,429</td>
<td>$</td>
</tr>
<tr>
<td>n, years 20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B RESERVE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set as percentage of loan repayment 25%</td>
<td>$2,045</td>
<td>$882</td>
<td>$20,607</td>
<td>$</td>
</tr>
<tr>
<td>C O&amp;M Costs - Annual</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basic Costs (Table 10-2)</td>
<td>$76,000</td>
<td>$76,000</td>
<td>$76,000</td>
<td>$76,000</td>
</tr>
<tr>
<td>Additional Costs this Alternative</td>
<td>$-</td>
<td>$-</td>
<td>$-</td>
<td>$-</td>
</tr>
<tr>
<td>D TOTAL COSTS (A +B+C)</td>
<td>$276,223</td>
<td>$270,410</td>
<td>$369,036</td>
<td>$266,000</td>
</tr>
</tbody>
</table>

WATER RATES

<table>
<thead>
<tr>
<th>Average Monthly Service Charge based on Number of Taps</th>
<th>Shell #3 and Shell #1 Pumping Systems</th>
<th>GWTP Improvements</th>
<th>New Well at North Cherry Anticline</th>
<th>Greybull Water System Base Charge*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1178</td>
<td>$19.54</td>
<td>$19.13</td>
<td>$26.11</td>
<td>$18.82</td>
</tr>
<tr>
<td>Increase in Monthly Service Charge</td>
<td>$0.72</td>
<td>$0.31</td>
<td>$7.29</td>
<td>$0.00</td>
</tr>
</tbody>
</table>

*: The $18.82 value is not the monthly service charge that the Town of Greybull charges its customers. It is a theoretical value based on existing debt obligations and O&M costs. It is used here to determine an approximate anticipated increase in service charge if the Town pursues funding of the alternatives presented.
CHAPTER 11
CONCLUSIONS AND RECOMMENDATIONS

Based on the information presented in this report, the project team provides the following conclusions for the Greybull Wells Rehabilitation, Level II, Study.

11.1 Conclusions

A. Source Supply

1. Future recompletion efforts at Greybull #1 are not warranted due to the large cost/high risk, demonstrated poor permeability of the Madison Limestone, and lack of geologic structure near the well.

2. Well rehabilitation efforts at Shell #3 have provided an additional 25 gpm of long-term artesian flow. During 2006, Shell #3 had a continuous artesian flow rate ranging from 125 to 150 gpm.

3. The Bighorn Dolomite is unlikely to provide sufficient additional artesian flow to warrant the cost and risk associated with future attempts to remove the blockage in the open hole interval of Shell #3.

4. Shell #3 can be pumped at a rate of 450 gpm with an anticipated depth to water during pumping of approximately 310 feet below ground surface.

5. Shell #1 can be pumped at a rate of 450 gpm with an anticipated depth to water during pumping of approximately 300 feet below ground surface.

6. Total artesian flow reduction at Shell #2, as a result pumping Shell #1 at a rate of 450 gpm, will be on the order of 70 to 80 gpm depending on the duration and frequency of pumping.

7. Net gain in water supply from the installation of pumps in Shell #1 and Shell #3 (each well pumping 450 gpm) will be approximately 490 gpm of instantaneous production.

8. Pumping systems in Shell #1 and Shell #3 could provide a total water supply of 1,770 gpm in the winter and 1,610 gpm in the summer, provide more operational flexibility to meet demands, and provide the opportunity for wells/aquifer to recover seasonally.
B. Supply and Demand

1. Revised estimates of water demand to the year 2030 indicate continuing supply deficits with respect to the maximum day demand (1,700 gpm with a 420 gpm deficit) and Chapter 12 WDEQ well production requirements (235 gpm deficit).

2. Pumping systems in Shell #1 and Shell #3 will alleviate current summer-time water supply shortages, satisfy WDEQ Chapter 12 well production requirements, and will also (just barely) satisfy projected maximum day demand to the planning horizon of 2030.

3. Participation in the Big Horn Regional Water System will provide supply redundancy in the event of emergencies and unforeseen increases in demand.

C. Evaluation of Greybull Water Transmission Pipeline

1. There is no systematic deterioration of the asbestos cement (AC) pipe along the Greybull Water Transmission Pipeline (GWTP). There is no evidence of sulfate attack and only minor to moderate acid attack at sporatic locations.

2. The failure rate and reliability of the GWTP will probably continue to be lower than for other similar AC pipelines.

3. 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.

4. The GWTP may be operated under the proposed future flow condition after modification of pipeline valves to maintain the maximum pressure in the line below 145 psi, but with reduced safety.

5. The GWTP is capable of delivering 1,500 gpm to the 1 MG tank while serving 300 gpm of peak demand to Shell Valley water users along the pipeline. Delivery of the additional flow will require modifications to existing valves and system operation.

6. The physical condition assessment and hydraulic modeling indicate that use of the existing GWTP, with modifications to existing pipeline valves and
pipeline operation, is a viable option to obtain additional water supplies capable of satisfying current and future water demands.

7. Under conditions modeled by future GWTP operation, some customers along the GWTP will experience pressure increases and some customers will experience pressure decreases during periods of maximum day/peak day. There will probably be a net benefit as some customers with current low pressure will experience higher pressure.

8. The most sensitive area along the GWTP is at the west end (Station 820+00 to 870+00) near the 1 MG tank where pressure decreases are likely to occur during periods of maximum day/peak day demand.

D. Economics and Financing

1. 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.

2. 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.

E. New Source Supply

1. 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.

2. It is anticipated that the well siting study will be used to assist the BHRWS in the exploration and development of groundwater resources at the north end of the regional water system.
11.2 Recommendations

The Level II study project team believes 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.
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