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TOWN OF TEN SLEEP
WATER SUPPLY PROJECT
LEVEL I MASTER PLAN REPORT
EXECUTIVE SUMMARY

Lidstone and Associates, Inc. (LA), in association with BRS Inc. (BRS), has completed its Level I investigation of the Ten Sleep water system. Ten Sleep is currently served by two, flowing artesian Madison Aquifer wells that provide adequate supply for the residential population. Based on original open flow test data, these wells are capable of supplying more than 4,000 gallons per minute (gpm) of good quality water. These wells are currently only adjudicated for a total of 850 gpm. The average daily water consumption is roughly 544 gallons per capita per day (gpcpd) or 171 gpm. This rate of consumption is roughly twice the average daily system use reported by the Wyoming Water Development Commission in the 2002 Water System Survey Report. Although these demands have yet to exceed system capacity, there have been instances where a significant drop in pressure has been experienced when both the park and cemetery have been irrigated simultaneously.

While residents connected to the Ten Sleep water system have enjoyed an abundant water supply, residents south of the city limits have historically had difficulty obtaining a reliable water supply that meets their needs both in terms of quantity and quality. While the deeper Paleozoic formations within the project area could possibly provide these residents with a good supply, the cost of drilling and constructing a deep well into the Tensleep, Madison, or Flathead Aquifers has been prohibitive. For this reason, it is the desire of these outlying residents to connect to the Ten Sleep water system.

The purposes of this investigation have been to document Ten Sleep’s existing water system and water use, to assess the feasibility of connecting additional residents to the south to the water system, and to provide recommendations for any necessary upgrades to the wells or water system for the next 30 years. In addition, this investigation has included a sonic leak detection survey to determine if excessive demands on the system are due to leakage.

Based on the data reviewed and additional fieldwork, LA has arrived at the following conclusions:

➢ The Ten Sleep water system currently serves 216 taps and approximately 454 residents. Growth forecasts for the area suggest the population may reach 496 people by 2030, but predicting the future growth of Ten Sleep is difficult due to the cyclical economic patterns experienced in Washakie County since 1960.

➢ Present and projected water demands were established on the basis of limited meter data from the 1990s. Ten Sleep’s average daily demand during the 1990s was 246,943 gpd or 544 gpcpd. Maximum daily demands have ranged up to 519,500 gpd or 1,144 gpcpd. Recent meter data collected in 2002 suggest present water demand for Ten Sleep averages 304,921 gpd or 672 gpcpd, but data from
both wells are only available for September. In 2030, average and maximum daily demands are projected to be 269,824 gpd, and 674,560 gpd, respectively.

Ten Sleep's water supply is primarily produced from the Madison Aquifer through two high capacity, flowing artesian wells. Ten Sleep No. 1 was completed to a depth of 1,050 feet in the Madison Limestone and Darwin Sandstone Member of the Amsden Formation, and has an adjudicated water right of 350 gpm under Permit No. U.W. 368 as of September 2, 1992. Ten Sleep No. 2 was completed to a depth of 1,098 feet in the Madison Limestone, and has an adjudicated water right of 500 gpm under Permit No. U.W. 48580 as of September 4, 1992. Recent aquifer testing of these wells indicates both are still capable of yielding moderate to large quantities of ground water to the water system. Artesian flows from both wells are currently metered.

Ten Sleep's transmission and distribution system consists of a combination of two and four inch diameter asbestos concrete and galvanized iron mains that were installed in the mid-1950s, and six, eight, and ten inch diameter PVC mains that were installed during the late 1970s. There are 216 unmetered taps on the water system, which is equipped with a sufficient number of adequately spaced fire hydrants. Information provided by the Town's utility and maintenance supervisor suggests that there may be numerous leaks in the older portions of the Town's water system.

While no leakage was detected on the main lines, valves, or hydrants in Ten Sleep or in route to the Shriver Subdivision, American Leak Detection (ALD) estimated the total service leakage to be 30-46 gpm or 95-146 gpcpd. Considering the historic average per capita water use of Ten Sleep is 544 gpcpd, approximately 17-27% of Ten Sleep's water use may be attributable to system leakage. All 18 leak locations were identified to on site personnel and located on maps of the town. On a cumulative basis, ALD reported that 21-35 gpm of these leaks are associated with the customer's side of the curb stop. Without a metering program in place, these users have limited incentive to repair leaks.

According to the EPA's Safe Drinking Water Violation Report, Ten Sleep has not been cited for any health-based water quality violations since at least 1993 despite the lack of any treatment.

Based on our review of the Ten Sleep water system, the principal problem appears to be the lack of sufficient water system capacity to meet maximum daily demand during the summer months, and system leakage estimated to be 95-146 gpcpd. LA has prepared conceptual designs and cost estimates for three alternatives to increase water system capacity and enhance the long-term viability of the water system. With this in mind, LA recommends Ten Sleep request WWDC funding of a Level II investigation to finalize the engineering design of the proposed water system upgrades. The alternatives developed as a result of this investigation include:
Installing a 500,000 gallon storage tank with an isolated eight inch diameter transmission line from the two wells, and an eight inch return line from the tank into the existing distribution system. This main will be reconnected into the existing system at locations just to the south of the existing two wells. This alternative will provide for the high demand fluctuations during the peak demand periods and equalize flows and pressures. Also included is a ten inch diameter transmission line that would serve users beyond the Shriver Park Subdivision and extend approximately two miles south from the subdivision along Wyoming State Highway 434.

Installing a 300,000 gallon storage tank that would not be sized for fire flows. In this alternative, Ten Sleep No. 2, the town’s highest yielding well, would be used exclusively to fill the storage tank, while Ten Sleep No. 1 and the storage tank would be used to supply the distribution system. Telemetry will be housed in a building adjacent to the tank. Also included is a ten inch diameter transmission line that would serve the eight to ten residents south of the Shriver Park Subdivision and extend approximately two miles south from the subdivision along Wyoming State Highway 434.

Replace the existing two inch galvanized iron and four inch asbestos concrete mains that are approaching the end of their design life with six-inch PVC mains. LA also recommends that existing dead end lines be looped where feasible, as it provides for expansion at a later date and eliminates any stagnant areas within the distribution system. Where it is not possible for line looping, flushing hydrants should be installed.

While increasing the overall capacity of the water system is the primary need at this time, LA recommends the town replace Ten Sleep No. 1 sometime within the next five to ten years to maintain adequate system redundancy, and abandon the original well. Furthermore, LA recommends Ten Sleep conduct a downhole video survey of this well to assess its current condition.
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1.0 INTRODUCTION

1.1 Project Background

The Town of Ten Sleep is currently served by two, flowing artesian Madison Aquifer wells that provide adequate supply for the residential population. Based on original open flow test data, these wells are capable of supplying more than 4,000 gallons per minute (gpm) of good quality water. These wells are currently only adjudicated for a total of 850 gpm. The average daily water consumption is roughly 544 gallons per capita per day (gpcpd) or 171 gpm. This rate of consumption is roughly twice the average daily system use reported by the Wyoming Water Development Commission in the 2002 Water System Survey Report. Although these demands have yet to exceed system capacity, there have been instances where a significant drop in pressure has been experienced when both the park and cemetery have been irrigated simultaneously.

While residents connected to the Ten Sleep water system have enjoyed an abundant water supply, residents south of the city limits have historically had difficulty obtaining a reliable water supply that meets their needs both in terms of quantity and quality. Cooley and Head (1979) reported the following regarding the residents’ experiences:

*Ground water of poor chemical quality has long been a problem to residents in the Nowood River Valley. Generally, very hard water containing large amounts of dissolved solids is present in the Triassic to Cretaceous sedimentary rocks and in the alluvial deposits that crop out in the river valley... Wells drilled through the flood-plain alluvium along the Nowood River also indicate that the alluvium is rather fine grained and that gravel occurs only in the bottom-most few feet. In general, thicknesses of the gravel reported by drillers’ logs range from only 5 to 11 feet. The small amount of gravel limits the quantity of ground water that can be obtained from wells completed in the alluvium.*

While the deeper Paleozoic formations within the project area could possibly provide these residents with a good supply, the cost of drilling and constructing a deep well into the Tensleep, Madison, or Flathead Aquifers has been prohibitive. For this reason, it is the desire of these outlying residents to connect to the Ten Sleep water system.

1.2 Purpose

The purposes of this investigation have been to document Ten Sleep’s existing water system and water use, to assess the feasibility of connecting additional residents to the south to the water system, and to provide recommendations for any necessary upgrades to the wells or water system for the next 30 years. In addition, this investigation has included a sonic leak detection survey to determine if excessive demands on the system are due to leakage.

LA’s investigation of Ten Sleep’s water system has focused on evaluating the existing system and developing alternatives to reduce water consumption through leakage or overuse. To complete this investigation, Lidstone and Associates, Inc. (LA) and BRS Inc. (BRS) have reviewed a variety of documents including the following: Wyoming State Engineer’s Office
reports, Wyoming Department of Environmental Quality/Water Quality Division (WDEQ/WQD) records, previous engineering reports, water system maps, and water usage data. In addition, LA and BRS conducted aquifer tests of the town’s wells, Ten Sleep No. 1 and Ten Sleep No. 2, and surveyed the existing distribution system. American Leak Detection (ALD) conducted a detailed leak detection survey of the water system in late October 2002. The following sections detail the methods used and results obtained during this investigation.
2.0 SERVICE AREA WATER USE AND WATER DEMANDS

2.1 Location

Ten Sleep is located approximately 26 miles east of Worland along U.S. Highway 16 in Washakie County. Located near the confluence of Ten Sleep Creek and the Nowood River in T47N, R88W, the town is situated at the base of Ten Sleep Canyon along the eastern margin of the Bighorn Basin, as shown on Figure 2.1. The local topography is relatively flat due to the town’s location within the flood plain of Ten Sleep Creek, and slopes gently toward the southeast.

Currently, there are no large industries or commercial establishments within Ten Sleep. The town is a mature residential community with a significant number of older people who reportedly live on fixed incomes. The area is comprised of arid to near desert grasslands that are devoted primarily to cattle ranching and sheep grazing. Irrigation is practiced along the riverbeds where hay is predominantly grown.

2.2 Population

Understanding current and predicting future water demand are critical components of this investigation for Ten Sleep. Water demand will govern the design of water production, transmission, storage, and distribution facilities for the next 30 years, which is the WWDC guideline. According to the U.S. Census Bureau, the population of Ten Sleep in 2000 was 304 people. However, Ten Sleep currently has a total of 216 taps attached to the water system, and serves a total population of 454 people. To determine project economics and assess Ten Sleep’s ability to pay, LA and BRS have tried to make a realistic appraisal of the existing population and the potential for future growth within the community.

Predicting the future growth of Ten Sleep is difficult primarily due to the cyclical economic patterns experienced in Big Horn County since 1960. The Ten Sleep area has a small labor force, is distant from large population areas, and lacks highly developed transportation and communication facilities. For these reasons any new industries or businesses are likely to be small and quite specialized. The source of past economic booms in the area, Oil, gas, and coal production seems unlikely to experience the periods of expansion it has in the past (Fox and Dolton, 1995). During the four decades from 1960 to 2000, Washakie County’s population declined by nearly 15% in the 1960s, rose by more than 25% in the 1970s, fell nearly 12% in the 1980s, and lost a little over one percent in the 1990s. Consequently, the likelihood of greatly increased labor demand in nearby towns, such as Worland, Manderson, or Basin, does not seem great. In fact, the U. S. Census Bureau (2002) has projected a continued population decline for Washakie County. As a result, a population increase of more than one hundred persons in the Ten Sleep area is considered unlikely to occur over the next two or three decades. Moderate growth that would raise the population by roughly thirty people over the next 30 years is considered most likely, as shown in Table 2.1.
FIGURE 2.1
Ten Sleep No. 1 and No. 2
Well Location Map
TABLE 2.1
Low, Moderate, and High Population Change Projections:
Town of Ten Sleep Service Area

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (5% decline)</td>
<td>454</td>
<td>431</td>
<td>410</td>
<td>388</td>
</tr>
<tr>
<td>Moderate (3% growth)</td>
<td>454</td>
<td>468</td>
<td>482</td>
<td>496</td>
</tr>
<tr>
<td>High (6% growth)</td>
<td>454</td>
<td>481</td>
<td>510</td>
<td>541</td>
</tr>
</tbody>
</table>

Note: 1 This number includes the population of Ten Sleep (304 residents from the 2000 census) and the surrounding area of (150 residents based on the 2000 census).

Nevertheless, Ten Sleep lies in a highly scenic area near the Bighorn Mountains, has a relatively mild climate, and could be attractive to second-home owners or retirees. It is this factor that appears to be most likely to spark any population growth in the area. Most land in the Ten Sleep area is federally owned and managed by either the U.S. Bureau of Land Management (BLM) or the U. S. Forest Service. Private land is located primarily along the Nowood River and its tributaries. In some locations property is currently available for residential development.

Patterns of land ownership, with most private land controlled by relatively large ranches, marginal roads, and distance from shopping areas, however, are likely to mitigate significant population growth. Subdivision of larger acreages in Washakie County is considered to be quite difficult. Some subdivision could occur, however, in almost any direction from Ten Sleep, but few such projects are likely to be large-scale unless ranch properties are subdivided. It seems unlikely that many of the larger ranch properties will be subdivided in the foreseeable future (BRS Communication with William Anderson, Nature Conservancy Superintendent).

2.3 Water Rights

Ten Sleep currently derives all of its municipal water supply from two wells completed in the Madison Aquifer. While Ten Sleep No. 1 and Ten Sleep No. 2 both have adjudicated water rights, there have been questions regarding the elimination of a large portion of each wells water right during the adjudication process. Water rights documentation for Ten Sleep Nos. 1 and 2 is included in Appendix A.

Although Ten Sleep No. 1 reportedly yielded 1,100 gpm following its construction in 1955, the well currently has an adjudicated water right of 350 gpm under Permit No. U.W. 368 as of September 2, 1992. The date of appropriation or priority for this well is April 21, 1955. The well is owned by the Town of Ten Sleep, and it is permitted for Municipal Use within the service area of the town as defined in Proof No. U.W. 3117. The service area and additional points of use are shown on Figure 2.2.
FIGURE 2.2

Ten Sleep Water System
Service Areas
At the time the WSEO inspected the well for adjudication on May 13, 1991, Ten Sleep No. 1 was equipped with an eight inch diameter Hersey in-line flowmeter. The Proof of Appropriation and Beneficial Use form (U.W. 8) indicates the amount of water being produced was determined from the flowmeter and a stopwatch. While running the water through the pressure-reducing valve, it appears the WSEO recorded a flow of 350 gpm. As a result of this adjudication, 750 gpm were eliminated from the water right attached to this well.

Ten Sleep No. 2 currently has an adjudicated water right of 500 gpm under Permit No. U.W. 48580 as of September 4, 1992. The date of appropriation or priority for this well is April 30, 1979. This well is also owned by the Town of Ten Sleep, and it is permitted for Municipal Use within the service area of the town as defined in Proof No. U.W. 3263.

When the WSEO inspected the well for adjudication on May 13, 1991, Ten Sleep No. 2 was equipped with an eight inch diameter Hersey flowmeter. The Proof of Appropriation and Beneficial Use form (U.W. 8) indicates the amount of water being produced was determined from the flowmeter and a stopwatch. While running the water through the pressure-reducing valve, it appears the WSEO recorded a flow of 500 gpm. As a result of this adjudication, 2,500 gpm of the original 3,000-gpm appropriation were eliminated from the water right attached to this well.

According to documentation included in Appendix A, former Mayor George McPherren had requested the elimination of a total of 3,250 gpm of water rights attached to these wells on August 12, 1991, but no documentation of reasons for this elimination was discovered. Subsequent correspondence between the town and the WSEO seems to reveal that none of the town council members or then Mayor Merle Funk were aware of the elimination until roughly October 1992. In subsequent years, Ten Sleep considered requesting an enlargement of its water rights, but to date, no enlargement has been applied.

2.4 Water Usage

Reports of Ten Sleep’s water usage have widely varied over the last couple years primarily because no daily or weekly meter records are available from 1994 to 2001, and because the meters at each of the wells failed within the last eight years. As recently as the 2002 Water System Survey Report to the WWDC, Ten Sleep reported average usage of 12,800 gallons per day (gpd) or 32 gpcpd, and maximum usage of 20,000 gpd or 50 gpcpd. However, in a recent survey completed for the Wind/Bighorn Basin planning project, the town reported average usage of 200,000 gpd or 500 gpcpd, and maximum usage of 600,000 gpd or 1,500 gpcpd. Ten Sleep currently has 216 taps and serves a population of 454 people. In an effort to establish actual historic usage, LA gathered all available electronic and paper records, and analyzed these records accordingly. The following sections detail the results of our records review.

2.4.1 Historical Use

Records of the town’s water usage are limited and incomplete. Detailed flowmeter records for both wells are only available from January 1992 through early 1995. Regular flowmeter readings for Ten Sleep No. 1 were resumed in July 2001, but were halted in August 2001 when
the flowmeter stopped functioning. The flowmeter in Ten Sleep No. 2 failed in December 1994. Flowmeters in Ten Sleep Nos. 1 and 2 were replaced in September 2002 and May 2002, respectively.

Available water meter and usage data from 1990, 1992-1995, and September 2002 were compiled into Table 2.2, and revealed the average usage for Ten Sleep has been 246,943 gpd or 544 gpcpd. Peak usage prior to 2002 was determined to be 504,571 gpd or 1,111 gpcpd. Variations in the historic water usage of Ten Sleep between 1992 and 1995 are shown graphically on Figure 2.3. Although Ten Sleep Nos. 1 and 2 are metered, there are currently no meters on the town's 216 taps. Leak detection is, therefore, not possible as an ongoing process. To assess whether excessive demands on the system are due to leakage, ALD conducted a sonic leak detection survey in late October 2002. Results of this survey are presented in Section 3.6.

### TABLE 2.2

**Historic Water Usage of Ten Sleep**

<table>
<thead>
<tr>
<th>Year</th>
<th>YEARLY AVERAGE DATA</th>
<th>MAXIMUM DAILY USAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total Gallons Per Day</td>
<td>Gallons Per Day Per Person</td>
</tr>
<tr>
<td>1990</td>
<td>265,753</td>
<td>585</td>
</tr>
<tr>
<td>1992</td>
<td>231,260</td>
<td>509</td>
</tr>
<tr>
<td>1993</td>
<td>254,989</td>
<td>562</td>
</tr>
<tr>
<td>1994</td>
<td>219,363</td>
<td>483</td>
</tr>
<tr>
<td>2001</td>
<td>205,374</td>
<td>452</td>
</tr>
<tr>
<td>2002</td>
<td>304,921</td>
<td>672</td>
</tr>
<tr>
<td>Average for all available data</td>
<td>246,943</td>
<td>544</td>
</tr>
</tbody>
</table>

Notes:  
1. Data for 1990 are from WSEO records and are reported as totals for the year. No daily meter records are available.  
3. These figures are estimated from the total flow from Ten Sleep No. 1 between December 1994 and July 2001. No daily meter readings were recorded for that well from that period; in 2001 only one reading was recorded in July for both wells; Ten Sleep No. 1 meter stopped functioning in August 2001.  
4. New meters installed at Ten Sleep No. 2 in May 2002, and at Ten Sleep No. 1 in September 2002. These data reflect water usage from September 10-30, 2002, when both meters were in operation.  
5. Based on a service area population of 454 residents. U.S. Census Bureau records indicate population of Ten Sleep was virtually unchanged between 1990 and 2000.  
N/A - Not available or not applicable.
Figure 2.3: Average discharge of Ten Sleep Nos. 1 and 2 since 1992. Notice the difference in average discharge, or water usage from the wells, between the periods of 1992-1995 and 2001-2002.

2.4.2 Current Water Demand and Billing Rates

Present water demand for Ten Sleep averages 304,921 gpd or 672 gpcpd, and peaks at 519,500 gpd or 1,144 gpcpd, as shown in Table 2.2. Comparison of current and historic average water usage reveals current demands are roughly 23.5% higher than historic average demand despite virtually no change in the service area population of Ten Sleep. These figures, however, may not reflect average daily demand for the year, as they were only collected during September 2002. This difference between the current and historic water demands is vividly illustrated on Figure 2.3. Because water consumption varies hourly, daily, and seasonally particularly in smaller communities, the following long term average water usage values were used to calculate peak hourly water demand:

- Average daily water usage..................246,943 gallons
- Average gallons per person per day..............544 gallons
- Average gallons per minute..........................171 gpm

Comparison of the long term average and maximum daily water usage reveals the maximum daily use is approximately 2.1 times the average daily use. This difference is within the
Wyoming State average, which ranges from 2.0 to 2.5, for comparably sized towns. Assuming peak hourly demand is four times the daily average, Ten Sleep has a peak hourly demand of 2,175 gpcpd or 686 gpm, well below Ten Sleep’s adjudicated water right of 850 gpm.

Ten Sleep currently has a total of 216 taps on its water system, 178 of which are in town taps and 38 of which are out of town taps. Of the out of town taps, eight are in the Shriver Park subdivision, which is located approximately one mile south of town along Wyoming State Highway 434, and 30 are located outside the corporate limits. Several residents, who live outside the corporate limits approximately two miles south of the Shriver Park subdivision along Highway 434, regularly fill water tanks for drinking water from a spigot at the town hall. These residents have requested to be included into the town’s distribution system due to the poor quality of any economically accessible domestic well water where they live. For reference, the current service area for the Ten Sleep water system is shown on Figure 2.2.

Compared to other water utilities in Wyoming, Ten Sleep’s water rates are very low. Currently, Ten Sleep charges its consumers the following water rates for unlimited use:

- Residents within the town: $12.00 per month
- Commercial facilities within the town: $15.00 per month
- Out of town residents: $16.00 per month

For comparison, Cheyenne currently charges a flat rate of $3.40 per month, plus $2.34 per additional 1,000 gallons. With a population of 600, Byron charges a base rate of $16.00, plus $2.00 per additional 1,000 gallons. The average bill for 20,000 gallons of water in Wyoming is $38.67. Historically, lower water costs have resulted in higher consumptive use rates.

Currently, Ten Sleep sells water on an as needed basis to the Pepsi plant in Worland. The town charges Pepsi $20.00/1,000 gallons and uses the additional revenue to repair and upgrade the water system. The recent upgrade of the wellhead plumbing on Ten Sleep No. 1 and installation of flowmeters at Ten Sleep Nos. 1 and 2 was funded through this revenue.

### 2.4.3 Fire Flows

An important function of a water system is its ability to provide adequate fire protection. Although actual amounts of water used for this purpose are usually small, rates of use are high. The National Board of Fire Underwriters (NBFU) recommends that communities such as Ten Sleep have a fire-fighting capacity of 1,500 gpm in the downtown commercial area, and 1,000 gpm in residential areas. These rates are for a two-hour period and residual pressures in the supply mains should not fall below 20 pounds per square inch (psi).

In Section 13D of Chapter 12 in the WDEQ Rules and Regulations, the WDEQ indicates “storage need not be provided in a well supply system where a minimum of two wells are provided and the maximum hour demand or fire demand, whichever is greater, can be supplied with the largest well out of service.” Assuming Ten Sleep’s best well, Ten Sleep No. 2, is out of service, Ten Sleep No. 1 will not provide sufficient flow to meet fire flow requirements. Based on aquifer testing under existing conditions, Ten Sleep No. 1 is only capable at this time of
yielding a maximum flow of 725 gpm at 46 psi wellhead pressure due to the restriction of the pressure reducing valve. Thus, the existing system under current conditions would not be able to meet the required fire flow conditions without creating negative pressures in the system.

2.4.4 Future Demand

Using the moderate growth estimate of 3% for a 30-year planning horizon, the projected service area population would be at 496 people in 2032. Assuming that average daily, maximum, and peak usage will increase proportionately with population, LA anticipates the future demand will be as shown in Table 2.3. Based on these projections, the existing wells will likely still be capable of meeting the new demands for the residential usage.

**TABLE 2.3**

*Future Water Demands For Ten Sleep in 2032*

<table>
<thead>
<tr>
<th>Water Use Profile</th>
<th>Projected Ten Sleep Water System Usage¹</th>
<th>Minimum WDEQ Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Daily Per Capita Use</td>
<td>544 gpcpd²</td>
<td>125 gpcpd</td>
</tr>
<tr>
<td>Average Daily Water Demand</td>
<td>188 gpm</td>
<td></td>
</tr>
<tr>
<td>Average Total Daily Water Use</td>
<td>269,824 gpd</td>
<td></td>
</tr>
<tr>
<td>Maximum Daily Water Use</td>
<td>674,560 gpd³</td>
<td></td>
</tr>
<tr>
<td>Maximum Daily Per Capita Use</td>
<td>1,360 gpcpd</td>
<td>340 gpcpd</td>
</tr>
<tr>
<td>Peak Hourly Demand</td>
<td>752 gpm³</td>
<td></td>
</tr>
</tbody>
</table>

Notes: ¹ Future demand estimated on the basis of a service area population of 496 people.
² Estimates assume current per capita usage continues in the future.
³ Assume maximum daily demand equals 2.5 times average daily and peak hourly averages 4 times average daily demand.
3.0 INVENTORY AND EVALUATION OF EXISTING SYSTEM

3.1 Water System Overview

Ten Sleep's water source is the Madison Aquifer, which is exposed along the western slope and uplands of the Bighorn Mountains in north central Wyoming. Ground water from this aquifer flows under artesian pressure to the town's system from two wells. Pressure regulators are required at both wells to reduce the wellhead pressure before entry into the distribution system, and to prevent damage to home plumbing components. While none of the town's water users are metered, new McCrometer transmission line flowmeters were installed at Ten Sleep Nos. 1 and 2 in September 2002 and May 2002, respectively. In addition, there is currently no tank storage in the system and no provision for disinfection.

Flow from the Madison Aquifer wells is distributed through the water system via a series of transmission and distribution lines that were installed in the mid-1950s and late 1970s. Much of the original distribution system from the 1950s appears to have been constructed using small diameter galvanized iron (GI) pipe. The original system was installed shortly after the installation of Ten Sleep No. 1. Information provided by the Town's utility and maintenance supervisor suggests that there may be numerous leaks in the older portions of the Town's water system. Several sections of the distribution system have been replaced with PVC pipe, but a fair portion is the original system that is approaching the end of its design life. Figure 3.1 depicts the Ten Sleep water system as of September 2002.

3.2 Madison Aquifer Wells

As mentioned previously, Ten Sleep's water supply is exclusively produced from the Madison Aquifer through two high capacity, flowing artesian wells. Because the town is solely supplied by ground water, the following sections provide a detailed overview of each well's as-built construction, yield, wellhead pressure, and water quality. Well completion reports and related documentation obtained from the WSEO for Ten Sleep Nos. 1 and 2 are included in Appendix B.

3.2.1 Ten Sleep No. 1 Completion

According to records obtained from the WSEO, Ten Sleep No. 1 was completed to a depth of 1,050 feet in the Madison Limestone and Darwin Sandstone Member of the Amsden Formation, as shown on Figure 3.2. At a cost of $15,602.56, this well was completed on February 2, 1955. The WSEO reports this well was constructed with four casings that extend to land surface, as shown on Figure 3.2, but no details were provided regarding the diameters of boreholes used for each casing, or the types of annular materials used to seal the well. The Madison Limestone and Darwin Sandstone production zone of this well is uncased from a depth of 749 to 1,050 feet. The location of the well relative to the town is shown on Figure 2.1.
FIGURE 3.1
Ten Sleep Existing Water Distribution System
WELL COMPLETION
T47N, R88W, SEC. 18 SW8W
COMPLETED FEBRUARY 2, 1955

LITHOLOGIC LOG

0-14' QUATERNARY ALLUVIUM:
Surface gravel, old terrace deposit

14-277' CHUGWATER FORMATION:
Red beds with gypsum beds

277-411' PHOSPHORIA FORMATION:
Porous limestone, some white; red beds,
some red sand and flint

411-625' TENSLEEP SANDSTONE:
Fine, mostly white, some pink. 60 gpm
good water

625-747' AMSDEN FORMATION:
Varicolored soft cavey shale, mostly dark
red, streaks of conglomeratic in the
bottom, very difficult to drill.

747-869' AMSDEN FORMATION:
DARWIN SANDSTONE MEMBER; fine, some
streaks hard; nearly all white, red at
top, limey at lower part. Flowing water
upper sandstones, increasing slightly in
lower sandstones, total from Amsden 52
gpm, pressure 115 pounds.

869-1,050' MADISON LIMESTONE:
White with streaks of blue-green shale,
mostly sandy. Extremely porous
limestone, brecciated and blue-green
shale fragments, some pure calcite
crystals and some small pyrite crystals.

NOTE:
Details of annular space completion are not available.
Completion interpreted from records of the State Engineer's
Office, and reports from Cooley (1986) and Eckelberg (2000).
Lithologic details from well driller's report.

NOTE:
Driller reported no more hole could be made, at 1,050 FT.
huge flow of water throughout rock fragments and jetted
six feet above top of casing, pressure flow over 1000
gpm. This and Amsden water together in hole, pressure
135 pounds.

FIGURE 3.2
Ten Sleep No. 1
Well Completion Diagram
Ten Sleep No. 1 yields flowing artesian ground water from the Madison Aquifer. While roughly 52 gpm is derived from the Darwin Sandstone, the majority of water produced from this well or approximately 1,050 gpm is obtained from the Madison Limestone. The static wellhead pressure when the well was completed in 1955 was reportedly 135 psi. According to Libra and others (1981), both the Darwin Sandstone and Madison Limestone in the well were tested on February 2, 1955. The flow test on the Darwin Sandstone was conducted for an uncertain duration of time to assess initial productivity. The test yielded 52 gpm with a drawdown of 265 feet for a specific capacity, or gallons per minute per foot of drawdown, of 0.2 gpm/ft. The flow test on the Madison Limestone was also conducted for an unspecified duration, but yielded 1,100 gpm with a drawdown of 311 feet for a specific capacity of 3.5 gpm/ft.

Although the completion report on file with the WSEF suggests the well was completed solely in the Madison Limestone, Cooley (1986) reported the well was a dual completion in the Madison Limestone and Tensleep Sandstone. The 8 5/8 inch diameter outer casing discharges water from the Tensleep at a rate reported in 1955 to be 60 gpm according to his report. Cooley recorded flow pressures on this casing to be 78 to 80 psi between 1962 and 1970. According to Cooley (1986), the 6 5/8 or 5 inch diameter inner casing discharges water from the Darwin Sandstone and Madison Limestone at rates up to 1,100 gpm at 135 psi. Based on the configuration of the wellhead prior to September 2002, it appeared the town was supplied exclusively with water from the Madison Aquifer.

Due to recent work on the wellhead in September 2002, it appears the isolation between the Tensleep and Madison Aquifers has been lost. Earlier in 2002, Ten Sleep contracted Municipal Supply Inc. (MS) of Hastings, Nebraska, to install a new gate valve on the wellhead and a new six-inch diameter McCrometer flowmeter on the transmission line to replace the meter that had quit functioning in August 2001. While the replumbing of the line improved access to the transmission pipeline components, MS installed the gate valve on the 8 5/8 inch diameter casing and attached the smaller 6 5/8 inch diameter casing to the larger 8 5/8 inch casing. As a result, there now appears to be potential for ground water from the Madison Aquifer to flow back into the Tensleep Aquifer even when the well is shut in. This hydraulic interconnection may ultimately lower the static wellhead pressure and reduce well yield.

During the course of this investigation, several site visits were made and the condition of the wellhead and well house were evaluated. Due to the recent modifications to the wellhead of Ten Sleep No. 1, the wellhead and transmission pipeline inside the well house appear to be in generally good condition.

3.2.2 Ten Sleep No. 1 Aquifer Testing

LA conducted a stepped rate aquifer test of Ten Sleep No. 1 to evaluate the artesian flow from the well under open discharge conditions, and estimate the current maximum yield. Aside from the initial flow test conducted by the driller, no other aquifer test data are available. Reported flows from this well are available from 1990; December 1991 through March 1995, and parts of 2001 and 2002. Average flows from the well during this time have ranged up to 519 gpm. Because the well is one of two sources of supply for Ten Sleep, LA and BRS arranged to open flow test the well in isolation from the transmission and distribution system. The well was shut
in at approximately 15:30 on September 12, 2002, and wellhead pressure was allowed to recover for roughly 30 minutes prior to starting the stepped rate test. Original data for this aquifer test are included in Appendix C with other historic test information.

For testing purposes, LA primarily utilized existing equipment associated with Ten Sleep No. 1, and isolated flow from the well from the distribution system by closing a couple valves. During the tests, artesian ground water flowing to land surface was transmitted through the existing transmission pipeline in the well house, and discharged from a fire hydrant located roughly 40 feet east of the well house via two, 2.5 inch diameter fire hoses. The water was discharged into an open field approximately 150 feet east of the fire hydrant. The discharge manifold adjacent to the wellhead, shown on Figure 3.3, was comprised primarily of six-inch diameter pipeline, a pressure-reducing valve (PRV), an inline flowmeter, and several gate valves. The gate valves were used to control flow from the well during the test. Discharge rates were monitored with a six inch diameter, analog, totalizing McCrometer flowmeter. During the stepped-rate flow test, wellhead and system line pressures in Ten Sleep No. 1 were measured with pressure gauges up and downstream of the PRV valve.

The stepped-rate flow test of Ten Sleep No. 1 was completed on September 12, 2002, following the initial recovery period when wellhead pressure rose to an approximate static level of 120 psi, or roughly 277 feet above land surface. The well was flow tested at successively higher rates of 238, 551, and 725 gpm. No attempt was made to maintain discharge rates after the first several minutes of each step. The highest discharge, which was attained with the gate valve wide open, represents the maximum discharge of the well under flowing conditions at the time of testing through existing infrastructure. LA believes the maximum yield of the well would have been greater if the PRV or some other obstruction had not been in the discharge line at the time of

![Figure 3.3: Photograph of Ten Sleep No. 1 and transmission line in the well house. The well is located in the background while the McCrometer flowmeter and gate valve are located in the foreground. Notice the locations of the wellhead and distribution system pressure gauges on the up and downstream ends, respectively, of the pressure-reducing valve. Picture taken September 12, 2002.](image-url)
testing. Ten Sleep No. 1 was allowed to flow at each of the three rates for approximately 30 minutes. Each step immediately followed the previous step such that there was no recovery of wellhead pressure between steps. At the end of the final step, the well was shut-in and wellhead pressure was allowed to recover. Recovery was monitored for 25 minutes.

### TABLE 3.1
**Ten Sleep No. 1**
**Stepped-Rate Flow Test Summary**

<table>
<thead>
<tr>
<th>Elapsed Time (min)</th>
<th>Discharge (gpm)</th>
<th>Wellhead Pressure (psi)</th>
<th>Drawdown As (ft)</th>
<th>Sc (gpm/ft)</th>
<th>Downstream PRV Pressure (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>238</td>
<td>106.5</td>
<td>31.19</td>
<td>7.6</td>
<td>&gt;100</td>
</tr>
<tr>
<td>30</td>
<td>551</td>
<td>61.5</td>
<td>135.14</td>
<td>4.1</td>
<td>56</td>
</tr>
<tr>
<td>30</td>
<td>725</td>
<td>46</td>
<td>170.93</td>
<td>4.2</td>
<td>39.5</td>
</tr>
<tr>
<td>25</td>
<td>0</td>
<td>119</td>
<td>2.31</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Results of the stepped-rate test are summarized numerically in Table 3.1, and time drawdown data for the test are presented graphically on Figure 3.4. Wellhead pressures for each step were measured and recorded on a logarithmic time schedule. This method allowed for more measurements to be recorded during the early part of each step when the wellhead pressure was changing rapidly. Drawdown, $\Delta s$, in the well was plotted versus time for each step, and specific capacities, $Sc$, at the end of each step were calculated to evaluate the yield of the well.

**Figure 3.4:** Time drawdown data for the stepped rate test of Ten Sleep No. 1 conducted on September 12, 2002. The last step of this test represents the maximum discharge of the well through the existing water system with the pressure-reducing valve turned off. This results in a yield of 725 gpm at a wellhead pressure of 46 psi.
Stepped-rate flow testing of Ten Sleep No. 1 revealed the well is still capable of yielding moderate artesian flows, and also indicated the specific capacity of the well has not diminished since well construction in 1955. As shown on Figure 3.5, comparison of aquifer test data collected in 1955 and 2002 reveals the specific capacity of the well has been maintained since construction. Most significantly, the sustainable yield of this well appears to be approximately 500 gpm based on short term testing.

![Specific Capacity Curve Comparison](image)

**Figure 3.5**: Specific capacity curve data for Ten Sleep No. 1 from 1955 and 2002. Notice that all discharge points generally fall along the same line. These data suggest the overall efficiency and yield of the well have not changed appreciably since the well was constructed in 1955.

### 3.2.3 Ten Sleep No. 2 Completion

As shown on Figure 3.6, Ten Sleep No. 2 was completed to a depth of 1,098 feet in the Madison Limestone according to records obtained from the WSEO. Layne-Western Company (Layne) of Denver, Colorado, drilled and completed the well between August 29 and September 22, 1978. Layne reportedly constructed this well with 62 feet of 13.375 inch diameter surface casing and 860 feet of 8.625 inch diameter casing, both of which were cemented in place, as shown on Figure 3.6. The Madison Limestone production zone of this well is uncased from a depth of 860 to 1,098 feet. The location of the well relative to the town is shown on Figure 2.1.
WELL COMPLETION
T47N, R88W, SEC. 17 NESE
COMPLETED SEPTEMBER 22, 1978

0-198' CHUGWATER FORMATION: Soft red shale; hard white limestone; light grey quartzitic sandstone; boulders & gravel; brown chert; dense dolomite

198-438' PHOSPHORIA FORMATION: Grey to pale lavender limestone; dense white & grey anhydrite; soft red shale; grey to clear chert; grey-green shale; red shaley siltstone. 1 to 2 gpm at 438'.

438-648' TENSLEEP SANDSTONE: Fairly soft pink & white sandstone; grey to purple dense limestone; trace grey to tan chert; buff limestone; some pyrite and soft white anhydrite. Water flow increased to approx. 40 gpm at 469-520'.

648-848' AMSDEN FORMATION: Grey to light purple limestone; red, maroon & yellow shale; white to grey sandstone; some pyrite chert.

848-1,098' MADISON LIMESTONE: White to grey & pink limestone; some grey to buff chert; some pyrite & white calcite; porosity at 1,045'. Flow of 150 gpm at 900'. Artesian flow increased to 200-225 gpm at 1,011'. Artesian flow of 3,000+ gpm beginning at 1,045'.

FIGURE 3.6
Ten Sleep No. 2
Well Completion Diagram
As with Ten Sleep No. 1, Ten Sleep No. 2 yields flowing artesian ground water from the Madison Aquifer. The static wellhead pressure when the well was completed in 1978 was reportedly 128 psi. Layne conducted a 24-hour open flow test of the well on September 21-22, 1978, to assess initial well yield. At the start of the test, the well yielded 3,900 gpm, but flow declined throughout the test and stabilized near 3,046 gpm with a total drawdown of 112 psi, or 258.72 feet, after 24 hours of uncontrolled open flow conditions. The specific capacity of the well was calculated to be 11.8 gpm/ft.

During the course of this investigation, several site visits were made and the condition of the wellhead and well house were evaluated. The wellhead and transmission pipeline inside the well house appear to be in very good condition. Recent work on the wellhead included the installation of a new six inch McCrometer flowmeter May 16, 2002. The previous flowmeter had stopped functioning on July 14, 2001.

3.2.4 Ten Sleep No. 2 Aquifer Testing

To evaluate the artesian flow from Ten Sleep No. 2 under open discharge conditions, and estimate the current maximum yield, LA conducted a stepped rate aquifer test of the well. Aside from the initial flow test by Layne, no other aquifer tests had previously been completed on this well. Reported flows from this well are available from 1990, December 1991 through March 1995, and parts of 2001 and 2002. Average flows from the well during this time have ranged up to 648 gpm. As with Ten Sleep No. 1, LA and BRS arranged to open flow test the well in isolation from the distribution system. The well was shut in at approximately 11:35 on September 12, 2002, and wellhead pressure was allowed to recover for roughly 20 minutes prior to starting the stepped rate test. Original data for this aquifer test are included in Appendix C along with other historic test data.

Figure 3.7: Photograph of Ten Sleep No. 2 and transmission line in the well house. The well is located in the background while the McCrometer flowmeter is located in the left foreground corner. Notice that pressure gauges are located on the wellhead to measure artesian pressure, and on the line downstream of the pressure reducing valve to measure distribution system pressure. Picture taken September 12, 2002.
For testing purposes, LA utilized the existing transmission line associated with Ten Sleep No. 2, and isolated flow from the distribution system by closing a couple valves and curb stops along Cottonwood and Sixth Streets. During the test, ground water from the well was transmitted through the existing transmission and distribution pipeline to two fire hydrants, where water was discharged via two, 2.5 inch diameter fire hoses. The water was discharged into Victoria Ditch under permission from the irrigation company. As with Ten Sleep No. 1, the discharge manifold adjacent to the wellhead, shown on Figure 3.7, was comprised primarily of six inch diameter pipeline, a PRV, an inline flowmeter, and several gate valves. The gate valves were used to control flow from the well during the test. Discharge rates were monitored with a six inch diameter, analog, totalizing McCrometer flowmeter. During the stepped-rate flow test, wellhead and system line pressures in Ten Sleep No. 2 were measured with pressure gauges up and downstream of the PRV.

The stepped-rate flow test of Ten Sleep No. 2 was completed on September 12, 2002, following the initial recovery period when wellhead pressure rose to an approximate static level of 119 psi, or roughly 275 feet above land surface. The well was flow tested at successively higher rates of 258, 476, 770, and 1,097 gpm. No attempt was made to maintain discharge rates after the first several minutes of each step. The highest discharge, which was attained with the gate valve wide open, represents the maximum discharge of the well under flowing conditions at the time of testing through existing infrastructure. Higher yields could have been attained had flows not been restricted by two, 2.5 inch diameter hose connections on the fire hydrants. Ten Sleep No. 2 was allowed to flow at each of the four rates for approximately 30 minutes. While the second and fourth steps immediately followed the previous step such that there was no recovery of wellhead pressure, the well was shut in following the second step to add additional fire hose to allow more water to flow from the well. At the end of the final step, the well was shut-in and wellhead pressure was allowed to recover. Recovery was monitored for 30 minutes.

**TABLE 3.2**

<table>
<thead>
<tr>
<th>Elapsed Time (min)</th>
<th>Discharge (gpm)</th>
<th>Wellhead Pressure (psi)</th>
<th>Drawdown Δs (ft)</th>
<th>Sc (gpm/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>258</td>
<td>117.5</td>
<td>3.47</td>
<td>74.4</td>
</tr>
<tr>
<td>30</td>
<td>476</td>
<td>114.5</td>
<td>10.40</td>
<td>45.8</td>
</tr>
<tr>
<td>20</td>
<td>0</td>
<td>118</td>
<td>2.31</td>
<td>--</td>
</tr>
<tr>
<td>30</td>
<td>770</td>
<td>109</td>
<td>23.10</td>
<td>33.3</td>
</tr>
<tr>
<td>30</td>
<td>1097</td>
<td>99</td>
<td>46.20</td>
<td>23.7</td>
</tr>
<tr>
<td>30</td>
<td>0</td>
<td>117.5</td>
<td>3.47</td>
<td>--</td>
</tr>
</tbody>
</table>

Results of the stepped-rate test are summarized numerically in Table 3.2, and time drawdown data for the test are presented graphically on Figure 3.8. Wellhead pressures for each step were measured and recorded on a logarithmic time schedule. This method allowed for more measurements to be recorded during the early part of each step when the wellhead pressure was...
changing rapidly. Drawdown, $\Delta s$, in the well was plotted versus time for each step, and specific capacities, $Sc$, at the end of each step were calculated to evaluate the yield of the well.

Stepped-rate flow testing of Ten Sleep No. 2 revealed the well is still capable of yielding large artesian flows, and also indicated the specific capacity of the well remains high since well construction in 1978. As shown on Figure 3.9, comparison of aquifer test data collected in 1978 and 2002 reveals the specific capacity of the well has been maintained since construction. Most significantly, the sustainable yield of this well appears to be more than 1,000 gpm based on short term testing.

![Figure 3.8: Time drawdown data for the stepped rate test of Ten Sleep No. 2 conducted on September 12, 2002. The last step of this test represents the maximum discharge of the well with the limitations imposed by the existing water system. Higher yields could be obtained from this well using additional four-inch diameter fire hoses attached to two hydrants.](image)

The isolated configuration of the well and distribution system during the stepped rate test revealed no significant leaks in this portion of the distribution system. While LA, BRS, and town personnel closed valves and shut off curb stops, the gate valve on Ten Sleep No. 2 was left wide open to allow free flow from the well. Once all the appropriate valves and curb stops had been closed, the flow from the well dropped to zero with the gate valve wide open. Because the flowmeter is only capable of measuring flows in excess of 90 gpm, it was clear that this portion of the distribution system along Cottonwood Street from north of Fourth Street to the well is free of any major leaks.
3.2.5 Wellhead and Distribution System Pressure History

To evaluate artesian pressure trends in the Madison Aquifer and their potential impact on flows from Ten Sleep Nos. 1 and 2, LA acquired wellhead pressure data from the WSEO and Ten Sleep personnel, and reviewed the locations of other high capacity wells in the vicinity of Ten Sleep. With the exception of 1955-1971 for Ten Sleep No. 1 and 1995-2001 for both wells, Ten Sleep has maintained relatively good records of both wellhead and distribution system pressures. Wellhead and distribution system pressures for the wells are shown on Figures 3.10 and 3.11, and tabulated information compiled for both wells is included in Appendix D along with water meter and usage data.

Based on the static wellhead pressures of Ten Sleep Nos. 1 and 2, it appears that the artesian pressure of the Madison Aquifer has not appreciably changed despite the presence of 16 other high capacity wells in the area. Comparison of wellhead pressure data recorded recently and those reported on the completion reports by the well drillers revealed virtually no difference in pressure since well construction. In between these points, however, wellhead pressures have fluctuated on a seasonal and a short-term basis, and well interference effects have been observed. These fluctuations are most conspicuous for Ten Sleep No. 1, as shown on Figure 3.10. Between 1972 and 1978, static wellhead pressures declined roughly 15 psi. Cooley (1986) reported that...
Figure 3.10:
Wellhead and distribution system pressures for Ten Sleep No. 1 from 1971 through 2002. Notice that while wellhead pressures have fluctuated on a seasonal and short term basis, there has been no appreciable long term decline in the wellhead pressure to date. Data used to compile this graph are tabulated in Appendix D.

Figure 3.11:
Wellhead and distribution system pressures for Ten Sleep No. 2 from 1978 through 2002. Notice that there has been no appreciable long term decline in the wellhead pressure to date. Data used to compile this graph are tabulated in Appendix D.
during this time the combined maximum yield of the East Spring and a well, both of which are located at the Wigwam Fish Rearing Station, declined approximately 250 gpm, or 20 gpm per one psi wellhead pressure decline at Ten Sleep No. 1. However, between 1980 and 1990 wellhead pressure rose approximately 25 psi. The impact of this rise in wellhead pressure upon flows at the Wigwam Fish Rearing Station was not reviewed. Similar but subtler trends are also noticeable for Ten Sleep No. 2, as shown on Figure 3.11. The locations of the 16 other high capacity wells are shown with respect to Ten Sleep Nos. 1 and 2 on Figure 3.12.

Due to the high artesian pressure of the Madison Aquifer near Ten Sleep, there is generally sufficient pressure in the transmission and distribution system to satisfy the local residents. Pressure regulating valves are required at both wells to keep distribution system pressures low enough to prevent damage to the system and to home related plumbing components. While Ten Sleep No. 1 wellhead pressures are reduced from 120/140 to 60/70 psi, Ten Sleep No. 2 pressures are reduced from 120/125 to 55/60 psi. During average usage periods, the Barton Residence at the south end of Chinese Elm Alley frequently experiences low-pressure problems. Several residents immediately west of Ten Sleep have reported low pressures during peak usage periods.

3.2.6 Water Quality

Ten Sleep is registered with the U.S. Environmental Protection Agency (EPA) as a community Public Water System (PWS) serving 311 people. The PWS identification for Ten Sleep’s water system is 5600203. As such an entity, Ten Sleep has established several sampling or monitoring points in town. These points include, but are not necessarily limited to, Ten Sleep Nos. 1 (WL01) and 2 (WL02), the Town Hall (SS01, SP01), the Town (DS01), and Kultz (SS02, SP02). Per EPA requirements, Ten Sleep currently submits monthly samples for total coliform analysis from each of 12 zones in town. According to the EPA’s Safe Drinking Water Violation Report, Ten Sleep has not been cited for any health-based water quality violations since at least 1993 despite the lack of any treatment or disinfection. A copy of this report and readily available detailed analytical reports for the town are included in Appendix E. General historic water quality data for Ten Sleep Nos. 1 and 2 are shown in Table 3.3.

Review of the data presented in Table 3.3 reveals the calcium bicarbonate type water derived from this well presents no corrosion threat to the well casing and minimal well yield reduction potential. WATEQ analysis of the water samples collected in September 2002 revealed water derived from both wells is slightly supersaturated with respect to calcite and dolomite, the principal mineralogical components of the Madison Limestone. This analysis in combination with hardness concentrations of 200-234 mg/l indicates water quality conditions in the well are favorable for some deposition of calcite and dolomite along fracture and other exposed surfaces including the well casing and distribution system pipes. This assessment is corroborated by Driscoll (1986) who indicated scale generally forms when water hardness is greater than 150 mg/l.
TABLE 3.3
Ten Sleep Nos. 1 and 2
Water Quality Comparison of Selected Analytes

<table>
<thead>
<tr>
<th>Well No.</th>
<th>Ten Sleep No. 1</th>
<th>Ten Sleep No. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12/17/73 Water</td>
<td>9/12/02 Water</td>
</tr>
<tr>
<td></td>
<td>10/12/77 Water</td>
<td>Sample</td>
</tr>
<tr>
<td></td>
<td>Sample</td>
<td>Sample</td>
</tr>
<tr>
<td>Analyte</td>
<td>Standards</td>
<td>9/28/78 Water</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9/12/02 Water</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sample</td>
</tr>
<tr>
<td>Calcium</td>
<td>45</td>
<td>42</td>
</tr>
<tr>
<td>Magnesium</td>
<td>25</td>
<td>22</td>
</tr>
<tr>
<td>Sodium</td>
<td>2.7</td>
<td>4.1</td>
</tr>
<tr>
<td>Potassium</td>
<td>2.1</td>
<td>2.6</td>
</tr>
<tr>
<td>Bicarbonate</td>
<td>250</td>
<td>220</td>
</tr>
<tr>
<td>Carbonate</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sulfate</td>
<td>250</td>
<td>18</td>
</tr>
<tr>
<td>Chloride</td>
<td>250</td>
<td>18</td>
</tr>
<tr>
<td>Nitrate</td>
<td>10.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Fluoride</td>
<td>1.4-2.4</td>
<td>0.3</td>
</tr>
<tr>
<td>TDS</td>
<td>500</td>
<td>238</td>
</tr>
<tr>
<td>Hardness</td>
<td>218</td>
<td>200</td>
</tr>
<tr>
<td>PH (s.u.)</td>
<td>6.5-9.0</td>
<td>234</td>
</tr>
<tr>
<td>Chromium</td>
<td>0.05</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Iron</td>
<td>0.3</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Lead</td>
<td>0.05</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Copper</td>
<td>1.0</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

Notes: Results listed in mg/l, unless noted otherwise. 
-- Indicates no analysis conducted for analyte. 
< Indicates analysis made, but analyte undetectable above concentration shown. 
Original copies of each laboratory sample above and others are attached in Appendix E.

3.3 Transmission and Distribution System

Ten Sleep's distribution system consists of two, four, six, eight, and ten inch diameter mains that are connected to individual service connections throughout the water system. These existing pipelines are made of various materials and are utilized in different lengths as follows: approximately 2,430 linear feet (LF) are ten inch diameter PVC mains; 11,400 LF are eight inch diameter PVC mains; 9,900 LF are six inch diameter PVC mains; 1,200 LF are four inch diameter AC mains; and 6,900 ft are two inch diameter GI mains.

The GI and AC mains appear to be more than 40 years old and were likely installed shortly after the installation of Ten Sleep No. 1. John W. Donnell & Associates (1977) estimated at that time that these two inch diameter GI and four inch diameter AC mains were over 20 years old. These lines are highly susceptible to leaks, requiring a fair amount of maintenance. LA recommends these be replaced as part of the ongoing upgrading of the system. Most of the PVC mains were installed in 1978 following the drilling and construction of Ten Sleep No. 2. These pipelines appear to be in relatively good condition. There are a total of 216 taps from these lines that service Ten Sleep's residents. Line locations are depicted on Figure 3.1, which illustrates the Ten Sleep water system as of September 2002.
3.4 Valves and Fire Hydrants

Review of the town’s system revealed there are an adequate number of fire hydrants around the town, which are well spaced within the town’s limits. The existing fire hydrants were tested for leaks. No leaks were detected and the fire hydrants were generally in good condition. For fire protection purposes, the town has six fire trucks that are manned by a volunteer fire department.

During the field investigation, LA attempted to locate most of the major valves in the existing water system. Not all the valves that are shown on earlier drawings were found. Existing known valves are shown in the drawing of the existing water system shown on Figure 3.1.

3.5 Water System Modeling

Ten Sleep’s water system was modeled using Haestad Method’s WaterCAD version 5.5. The WaterCAD program uses elements such as tanks, reservoirs, control valves, pumps, nodes and pipes to simulate different water distribution systems. Waterline lengths, sizes and material were obtained from as-built maps provided by the town of Ten Sleep, as shown on Figure 3.1. Projected flows for the 30-year usage were used in the existing system model and applied equally to all 62 junctions that were used in the model. A summary of the results is shown in Table 3.4 on Figure 3.13 along with referenced junction locations.

Pressures in the existing system with the projected 30-year population will be adequate for the town. With a storage tank, system pressure will increase as will the ability to incorporate additional residents from outside the town’s corporate limits. The fire fighting capability will also be met with a storage tank.

3.6 Leak Detection Testing

American Leak Detection (ALD) of Billings, Montana, conducted a system leak survey in Ten Sleep during the week of October 21-28, 2002. The survey was performed by electronically testing all accessible valves, hydrants, and curb stops for vibration indicative of leakage. Many curb stops were electronically located and excavated for testing. Approximately 5.75 miles of main water lines were also surveyed for leaks at six foot intervals using a ground vibration survey.

While no leakage was detected on the main lines, valves, or hydrants in Ten Sleep or in route to the Shriver Subdivision, ALD estimated the total service leakage to be 30-46 gpm or 95-146 gpcpd. Considering the historic average per capita water use of Ten Sleep is 544 gpcpd, approximately 17-27% of Ten Sleep’s water use may be attributable to system leakage. All 18 leak locations were identified to on site personnel and located on maps of the town. On a cumulative basis, ALD reported that 21-35 gpm of these leaks are associated with the customer’s side of the curb stop. Without a metering program in place, these users have limited incentive to repair leaks. Detailed results of this survey are included in ALD’s report that is included in Appendix F.
TABLE 3.4

<table>
<thead>
<tr>
<th>JUNCTION NO.</th>
<th>PRESSURES FOR EXISTING SYSTEM IN THE YEAR 2032 (psi)</th>
<th>PRESSURES FOR EXISTING SYSTEM IN RESIDENTS +/- 2 MILES SOUTH OF THE SCHRIVER SUBDIVISION (psi)</th>
<th>PRESSURES FOR EXISTING SYSTEM WITH PROPOSED ISOLATED TRANSMISSION LINE AND STORAGE TANK (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>J-1</td>
<td>48</td>
<td>48</td>
<td>62</td>
</tr>
<tr>
<td>J-2</td>
<td>65</td>
<td>65</td>
<td>78</td>
</tr>
<tr>
<td>J-3</td>
<td>73</td>
<td>73</td>
<td>87</td>
</tr>
<tr>
<td>J-4</td>
<td>77</td>
<td>77</td>
<td>90</td>
</tr>
<tr>
<td>J-5</td>
<td>43</td>
<td>43</td>
<td>57</td>
</tr>
<tr>
<td>J-6</td>
<td>47</td>
<td>47</td>
<td>54</td>
</tr>
<tr>
<td>J-7</td>
<td>63</td>
<td>63</td>
<td>76</td>
</tr>
<tr>
<td>J-8</td>
<td>48</td>
<td>48</td>
<td>63</td>
</tr>
</tbody>
</table>

This flow was divided equally amongst the nodes used in the model (62 junctions).

FIGURE 3.13

Town of Ten Sleep Pressure Junction Locations

Junctions J-8 and J-9 located approximately 2 miles south of the Schriver sub-division.
3.7 System Operation

Ten Sleep’s water system is operated on an on-demand basis. While PRV’s are used to reduce wellhead pressure and the flow from each well, artesian flows from Ten Sleep Nos. 1 and 2 are piped directly to the water system. Transmission lines at the wellheads are equipped with gate valves to control flow, but are generally left wide open to provide flow on demand, and to fully pressurize the system at all times. In this scenario, Ten Sleep uses the Madison Aquifer as its storage reservoir, and relies on well flows and whatever storage is immediately available in the well bore and water system pipeline to meet existing demand. Historically, Ten Sleep No. 1 has been used to provide the majority of the town’s water supply, despite the higher yield available from Ten Sleep No. 2.
4.0 ANALYSIS OF WATER SYSTEM ALTERNATIVES

4.1 General

The preceding sections detailed the findings of our investigation into the existing water system for Ten Sleep. LA’s review of the water system revealed several existing problems and potential problems that will likely need to be addressed at some point during the next 30 years. These problems include:

- The lack of a storage tank to offset well yield requirements during maximum demand periods, to provide system balance and limited redundancy if a well were to fail, and to provide fire protection.
- The presence of two inch diameter GI and four inch diameter AC mains in the distribution system that are more than 40 years old and have likely exceeded their design life. These lines are highly susceptible to leaks, requiring a fair amount of maintenance, and could already be a source of leakage from the system.
- The age and fragility of Ten Sleep No. 1, which was originally completed more than 47 years ago and has surpassed its original design life. This well should be replaced sometime within the next five to ten years to maintain adequate system redundancy.

The purpose of this section is to address these problems and concerns, and provide several options for improving the water system.

4.2 Water Quality and Implications of the GWR

While Ten Sleep has not been cited for any health-based water quality violations since at least 1993, the EPA is currently developing a Ground Water Rule (GWR) to reduce public health risk associated with the consumption of waterborne pathogens from fecal contamination. The EPA initially published the proposed GWR in the Federal Register on May 10, 2000, under 40 CFR Parts 141 and 142. A copy of the proposed GWR is included in Appendix G. While only a small percentage of ground water systems are likely fecally contaminated, the EPA believes the number of people and the severity of the health impacts of water borne disease upon young children, elderly, and others warrants a regulatory response. It is anticipated that the final GWR will be delivered in March 2003 with a statutory deadline of July 2003.

Ten Sleep is likely to be impacted by the GWR to some degree because the community is served solely by ground water and because the community does not currently disinfect the water supply. Under the GWR, the EPA would require Ten Sleep to conduct some or all of the following:

- A system Sanitary Survey every three years to address the eight elements from joint EPA and Association of State Drinking Water Administrators guidance document.
One Hydrogeologic Sensitivity Assessment within six years of the final GWR date of publication to assess the sensitivity of the Madison Aquifer to fecal contamination.

Routine monthly Source Water Monitoring. Sampling frequency may be reduced after 12 negative samples.

Corrective Actions contingent upon fecal coliform detection.

Daily Compliance Monitoring contingent upon disinfection to avoid source water monitoring.

The overall impact of the GWR is likely to be minimal, but is ultimately still uncertain. At a minimum, the EPA will require Ten Sleep conduct a Sanitary Survey every three years and one Hydrogeologic Sensitivity Analysis. LA believes the EPA will also require monthly source water monitoring because the Madison Aquifer is known to be sensitive to fecal contamination due to its fracture and karst permeability, and high ground water flow rates. Currently, Ten Sleep is required to perform monthly total coliform monitoring and has been consistently conducting Sanitary Surveys every three years. Provided Ten Sleep continues to receive analytical reports indicating there is no fecal coliform in the water system, the only additional requirement appears to be the one-time Hydrogeologic Sensitivity Analysis. With regard to whether disinfection or treatment will be required, however, EPA Region 8 personnel in Denver, Colorado, will ultimately make that decision based on a variety of issues (Personal communication with Phil Burger, EPA).

4.3 Installation of a Storage Tank and Isolated Transmission Line

The primary purposes for water storage are to offset well yield requirements during maximum demand periods, to provide system balance and limited redundancy if a well were to fail, and to provide fire protection. As discussed in Section 2.4.3, Ten Sleep No. 1 cannot produce sufficient artesian flows under existing conditions to meet NBFU or WDEQ requirements for fire flows. Hence, LA recommends installing a storage tank and an isolated transmission line, as shown on Figure 4.1.

WDEQ requirements for water systems serving an average daily demand of 50,000 to 500,000 gallons are to provide storage for the average daily demand plus fire storage, as established by the local fire agency or fire Marshall. The fire code for towns the size of Ten Sleep requires 1,500 gpm in a commercial area, and 1,000 gpm in residential areas with single and two story homes. Several scenarios are presented in Table 4.1 to meet or approach these storage requirements.
TABLE 4.1  
Current and Future WDEQ Storage Requirements  
For the Ten Sleep Water System

<table>
<thead>
<tr>
<th>CURRENT STORAGE REQUIREMENTS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire flows: 1,500 gpm for 2 hours</td>
<td>180,000 gallons</td>
</tr>
<tr>
<td>Present population of 454 @ 544 gpcpd</td>
<td>246,796 gallons</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>426,976 gallons</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2032 STORAGE REQUIREMENTS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire flows: 1,500 gpm for 2 hours</td>
<td>180,000 gallons</td>
</tr>
<tr>
<td>Projected population of 496 @ 544 gpcpd</td>
<td>269,824 gallons</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>449,824 gallons</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2032 STORAGE REQUIREMENTS USING WYOMING AVERAGE OF 285 gpcpd</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire flows: 1,500 gpm for 2 hours</td>
<td>180,000 gallons</td>
</tr>
<tr>
<td>Projected population of 496 @ 285 gpcpd</td>
<td>141,360 gallons</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>321,360 gallons</td>
</tr>
</tbody>
</table>

Notes: 1 See Tables 2.2 and 2.3 for reference.

These storage estimates in Table 4.1 are based on the current consumption of the town whose residents have unlimited use for a flat monthly rate. To provide fire flows and meet usage requirements under current conditions, LA recommends a storage tank capacity of 500,000 gallons. Storage requirements without fire flows currently and in 2032 would require a tank capable of holding 269,824 gallons. For this option, LA recommends a 300,000 gallon tank. If usage could be reduced to average levels throughout Wyoming through the use of meters, then storage requirements for 2032, including fire flows, would necessitate a 330,000 gallon storage tank.

The addition of a storage tank and isolated transmission line would also enable additional users to be brought onto the town’s distribution system without affecting the current production or usage. However, WDEQ will require provision for disinfection of the water system upon installation of a storage tank based on Section 13A, xi of Chapter 12. Thus, the addition of a storage tank will require chlorine injection equipment. Telemetry for the system will require a building adjacent to the tank.

4.4 Replacement of Ten Sleep No. 1

Due to the age and relatively fragile condition of Ten Sleep No. 1, LA recommends the town replace this well sometime within the next five to ten years to maintain adequate system redundancy. Ten Sleep No. 1 was originally completed more than 47 years ago on February 2, 1955 and has surpassed the original design life. Recent work on the well in September 2002 revealed the near surface well casing is in reasonably good condition, but also indicated the bottom of the inner most five inch diameter casing was poorly, if at all, supported by the Amsden Formation. Completion records are poor and conflicting. While there have been no reports of sediment discharge from the well that would clearly reveal the formation of a cavity downhole,
Ten Sleep personnel reported that MS had difficulty cutting the five inch casing because it was moving downhole. The original near surface well piping for Ten Sleep No. 1 is shown on Figure 4.2 with various saw cuts. While the outer 8 5/8 and 6 5/8 inch casings have been pinned together, the five inch casing was not attached to one of the other casings. At this point, it is uncertain to what extent, if any, this casing may continue to move downhole.

Figure 4.2:
Photograph of the original wellhead casing that was cut from Ten Sleep No. 1 in September 2002. The 8 5/8, 6 5/8, and 5 inch diameter casings are shown nested here, as they had been installed in the well. Notice that a couple of different saw cuts are visible on the 5-inch diameter casing.

Furthermore, LA recommends Ten Sleep replace the well to prevent the potential loss of artesian flow and pressure from the Madison Aquifer due its potential interconnection with the Tensleep Aquifer through this well. Cooley (1986) reported the well was a dual completion in the Madison Limestone and Tensleep Sandstone prior to the work completed in September 2002. However, once MS installed the gate valve on the 8 5/8 inch diameter casing, the isolation between the Tensleep and Madison Aquifers that had reportedly been maintained through the different casings appears to have been lost. Due to the lack of information regarding the types of and depths at which annular materials were used to seal the well, it is also possible that these two aquifers have been interconnected since the well was constructed.

A replacement well for Ten Sleep No. 1 could likely be drilled and completed successfully at a location offset close to the existing well. An 1,100-foot deep replacement well completed with 8 5/8 inch diameter casing grouted into the top of the Madison Limestone would likely yield a good redundant supply well that would be serviceable for 30 years or more. A conceptual design of this well would be very similar to that of Ten Sleep No. 2, shown on Figure 3.6
4.5 Replacement and Abandonment of Water Lines

Since the existing two inch galvanized iron mains are approaching the end of their design life, LA recommends the town upgrade the two inch GI mains, which tend to develop leaks requiring constant repairs. It is recommended that these pipelines be replaced with six inch diameter PVC mains, as shown on Figure 4.3, and that dead end lines be looped wherever possible. The areas requiring replacement are as follows:

- The two inch main along Ponderosa Alley.
- Replace the two inch GI pipe along Maple Alley that feeds into the Valley Motel. This pipe has been repaired on a number of occasions during the past few years.
- The two inch GI main along Aspen Alley.
- The two inch GI main from the corner of Cottonwood and Second Streets to the south end of Cottonwood Street should be replaced with a six inch PVC main.
- The two inch GI main from the south end of Cottonwood Street that goes under the river and reconnects with the eight inch PVC along Highway 434 south of town should be abandoned, as there is already a ten inch PVC main running parallel to it that was installed in 1979. The residents that are currently being serviced by the two inch GI main will need to be connected onto the existing ten inch main.
- The four inch AC line along Maple Alley, between Pine and Cottonwood streets should be replaced with a six inch PVC main.
- The polyethylene main along Pine Street between Second and Third Streets should be replaced with a six inch PVC main.
- Replace the two inch GI main to the county maintenance shop on Highway 434 with a six inch PVC main.

4.6 Construct Additional Transmission Line to Service Southern Residents

LA recommends the town provide water to the approximately eight to ten users two miles south of the Shriver Park subdivision along the Highway 434. Current residents are transporting water from the town for their daily use. The location of the proposed pipeline extension is shown on Figure 4.4. This level of regionalization will provide outlying residents with a viable water supply, which meets Federal and State standards. It can be done so without adversely affecting system pressures or the available quantity of water to other town users. It will also assist the Town’s ability to pay for other system upgrades based on new tap fees and out of town rates.

4.7 Install Water Meters

Due in part to the low monthly cost for water in Ten Sleep and estimated total service leakage of 95-146 gpcpd, the average water usage of 544 gpcpd is almost twice the Wyoming average of 285 gpcpd. This high water usage peaks during the summer months and results in lower pressures and declining flows in some areas around town. Installing water meters is a way for residents to bring their consumption in line with the Wyoming average and would also ensure that there will be adequate flows during peak times within the town. Meters are also a good way
PROPOSED TEN SLEEP WATER LINES.

PROPOSED UPGRADE AREAS: 6 IN PVC LINE TO REPLACE OLD LINES

PROPOSED GATE VALVES
to assess leaks in the future. Thus it is a recommendation that water meters be installed throughout the town. The additional revenues generated would enable the town to pay for the loan required for the implementation of these improvements. Several State and Federal grant/loan assistance scenarios require meters on each town’s water distribution network.
5.0 RECOMMENDED ALTERNATIVES

Based on our review of the Ten Sleep water system, the principal problems appear to be the lack of sufficient water system capacity to meet maximum daily demand during the summer months, and system leakage estimated to be 95-146 gpcpd. LA has prepared conceptual designs and cost estimates for three alternatives to increase water system capacity and enhance the long-term viability of the system. While the advantages and disadvantages of each of these alternatives are discussed further in the following paragraphs, LA recommends Ten Sleep request WWDC funding of a Level II investigation to finalize the engineering design of the proposed water system upgrades.

5.1 Alternative No. 1 – Installation of a New 500,000 Gallon Storage Tank with Isolated Transmission Lines

LA recommends Ten Sleep install a 500,000 gallon storage tank, and construct an isolated eight inch transmission line from the two wells to the tank and an eight inch return line extending from the tank to the existing distribution system, as shown on Figure 4.1. This main will be reconnected to the existing system at locations just south of the existing wells. This alternative will also include a building adjacent to the new tank for the telemetry from the tank to the wells. These improvements will equalize flows and pressures experienced during high demand periods. In addition, this alternative includes a ten inch diameter transmission line from the Shriver Park Subdivision, via Wyoming State Highway 434, to a point approximately two miles south.

This alternative has several advantages that will benefit the town and residents beyond the city limits. In addition to supplying fire flows, this alternative will provide residents beyond the Shriver Park subdivision with a water supply. These improvements will buffer the supply during periods of high demand, and allow expansion to the existing system at a later date. As per WDEQ regulations for storage tanks, however, chlorination equipment will need to be installed for the purpose of disinfecting the water supply entering the tank.

5.2 Alternative No. 2 – Installation of a New 300,000 Gallon Storage Tank

During LA’s investigation of Ten Sleep’s water system, it was discovered that Ten Sleep No. 2 often was not flowing, and that only Ten Sleep No. 1 was supplying the town during low demand periods. To better utilize this well, this alternative would utilize ground water exclusively from Ten Sleep No. 2 to fill a 300,000 gallon storage tank that would not be sized for fire flows, as shown on Figure 5.1. In this alternative, the distribution system would be supplied from both the storage tank and Ten Sleep No. 1. Telemetry to control the flow of water to the storage tank will be housed in a building adjacent to the tank.

While this alternative will not provide for fire flows, it will ensure that the town has adequate supply during those periods of high demand, and also provide water to the residents south of the Shriver Park Subdivision. As per the WDEQ regulations, disinfection will need to be provided and can be injected into the supply water through a chlorination system from inside the well houses.
PROPOSED TEN SLEEP WATER LINES

- PROPOSED 8 INCH PVC TRANSMISSION LINE TO TANK
- PROPOSED 8 INCH PVC TRANSMISSION LINE FROM TANK
- EASEMENT BOUNDARY
- EXISTING LINES (FOR REFERENCE TO PROPOSED CHANGES ONLY)
- PROPOSED GATE VALVE

PROPOSED 8 INCH PVC TRANSMISSION LINE FROM TANK TO EXISTING SYSTEM
PROPOSED 300,000 GALLON STORAGE TANK

20 FT. EASEMENT

WELL TO BE DISCONNECTED FROM EXISTING SYSTEM
DISCHARGE TO WASTE HYDRANT W/ VALVE
TIE INTO WELL 2

CITY CORPORATE BOUNDARY

EXISTING LINES (FOR REFERENCE TO PROPOSED CHANGES ONLY)

PROPOSED GATE VALVE

PROPOSED TEN SLEEP WATER LINES

TEN SLEEP

FIGURE 5.1
Proposed Isolated Transmission Lines and A 300,000 Gallon Storage Tank for Ten Sleep - Well 2 Only

Project No. WMYMC102
Date: 12/12/2012
Designer: JLR
Draft: JP
Checker: SW
File: TENLWDP-813.00w
This alternative is less costly, and as the town’s needs grow, an additional 200,000-gallon tank can be added at a later date. The advantage of having two tanks is primarily redundancy, which would allow for one tank to be taken out of service for maintenance or repairs, as needed, without adversely affecting the water supply for the town.

5.3 Alternative No. 3 – Upgrading of the Existing Distribution System.

Since the existing two inch galvanized iron and four inch AC mains are approaching the end of their design life, LA recommends the town replace these mains. Pipes constructed of these materials and of this age tend to develop leaks requiring constant repairs. Because the cost of four inch and six inch diameter pipe is insignificant compared to the costs of excavation, backfilling and compaction during construction, LA recommends that these be replaced with six inch PVC mains, as shown on Figure 4.3.

LA also recommends that existing dead end lines be looped where feasible, as this will provide for any expansion at a later date and eliminate any stagnant areas within the distribution system. Where it is not possible for line looping, flushing hydrants should be installed. Disinfection for the distribution system can be supplied from the well houses.
6.0 CONCEPTUAL DESIGNS AND COST ESTIMATES

Preliminary estimates of costs to construct the various alternatives proposed in Section 5.0 are presented below in Tables 6.1 through 6.4. These estimates include the actual costs to complete the physical installation of each alternative, in addition to associated engineering fees for design, plans, and specifications. As such these estimates include capital costs only and do not include costs related to operation and maintenance upon completion of each alternative.

6.1 Alternative No. 1 – Installation of a New 500,000 Gallon Storage

Alternative No. 1 includes a 500,000 gallon storage tank with an isolated eight inch transmission line from the two wells, an eight inch return line from the tank into the existing distribution system, and a ten inch transmission line from the Shriver Park Subdivision, via Wyoming State Highway 434, to a point approximately two miles south. This alternative will also include a building adjacent to the new tank for the telemetry from the tank to the wells.

**TABLE 6.1**

**Preliminary Estimate of Level III Costs for Alternative No. 1**

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Estimated Quantity</th>
<th>Unit Price</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobilization</td>
<td>L.S.</td>
<td>1</td>
<td>$50,000.00</td>
<td>$50,000.00</td>
</tr>
<tr>
<td>New Transmission Main to Tank with Return Main in same Trench</td>
<td>L.F.</td>
<td>5,200</td>
<td>$18.00</td>
<td>$93,600.00</td>
</tr>
<tr>
<td>500,000 Gallon Tank and Foundation</td>
<td>L.S.</td>
<td>1</td>
<td>$245,000.00</td>
<td>$245,000.00</td>
</tr>
<tr>
<td>Ten Inch Transmission Line From Shriver Sub-division</td>
<td>L.F.</td>
<td>12,000</td>
<td>$28.00</td>
<td>$336,000.00</td>
</tr>
<tr>
<td>Fittings and appurtenances</td>
<td>L.S.</td>
<td>1</td>
<td>$20,000.00</td>
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</tr>
<tr>
<td>Telemetry Building</td>
<td>L.S.</td>
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<td>$20,000.00</td>
<td>$20,000.00</td>
</tr>
<tr>
<td>Telemetry/Power Supply</td>
<td>L.S.</td>
<td>1</td>
<td>$12,000.00</td>
<td>$12,000.00</td>
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<tr>
<td><strong>SUBTOTAL (1)</strong></td>
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<tr>
<td><strong>ENGINEERING 10% OF SUBTOTAL (1)</strong></td>
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<td>$77,660.00</td>
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<td><strong>SUBTOTAL (2)</strong></td>
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<td>$854,260.00</td>
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<td><strong>CONTINGENCY @ 15% OF SUBTOTAL (2)</strong></td>
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<tr>
<td><strong>TOTAL CONSTRUCTION COSTS</strong></td>
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<td><strong>SURVEYING</strong></td>
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<td><strong>PERMITTING COSTS</strong></td>
<td></td>
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<td></td>
<td>$15,000.00</td>
</tr>
<tr>
<td><strong>FINAL PLANS AND SPECIFICATIONS</strong></td>
<td></td>
<td></td>
<td></td>
<td>$80,000.00</td>
</tr>
<tr>
<td><strong>TOTAL COST</strong></td>
<td></td>
<td></td>
<td></td>
<td>$1,092,399.00</td>
</tr>
</tbody>
</table>

Lidstone and Associates, Inc.
December 1, 2002
6.2 Alternative No.2 – Installation of a New 300,000 Gallon Storage Tank

To better utilize Ten Sleep’s most productive well, Alternative No. 2 utilizes ground water exclusively from Ten Sleep No. 2 to fill a 300,000 gallon storage tank that would not be sized for fire flows. Telemetry to control the flow of water to the storage tank will be housed in a building adjacent to the tank. In this alternative, the distribution system would be supplied from both the storage tank and Ten Sleep No. 1. A ten inch transmission line from the Shriver Park Subdivision, via Wyoming State Highway 434, to a point approximately two miles south is also included in this alternative.

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Estimated Quantity</th>
<th>Unit Price</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobilization</td>
<td>L.S.</td>
<td>1</td>
<td>$50,000.00</td>
<td>$50,000.00</td>
</tr>
<tr>
<td>New Transmission Main to Tank with Return Main in same Trench</td>
<td>L.F.</td>
<td>2,000</td>
<td>$18.00</td>
<td>$36,000.00</td>
</tr>
<tr>
<td>300,000 Gallon Tank and Foundation</td>
<td>L.S.</td>
<td>1</td>
<td>$147,000.00</td>
<td>$147,000.00</td>
</tr>
<tr>
<td>Ten Inch Transmission Line From Shriver Sub-division</td>
<td>L.F.</td>
<td>12,000</td>
<td>$28.00</td>
<td>$336,000.00</td>
</tr>
<tr>
<td>Fittings</td>
<td>L.S.</td>
<td>1</td>
<td>$40,000.00</td>
<td>$40,000.00</td>
</tr>
<tr>
<td>Telemetry Building</td>
<td>L.S.</td>
<td>1</td>
<td>$30,000.00</td>
<td>$30,000.00</td>
</tr>
<tr>
<td>Telemetry/Power Supply</td>
<td>L.S.</td>
<td>1</td>
<td>$12,000.00</td>
<td>$12,000.00</td>
</tr>
</tbody>
</table>

**SUBTOTAL (1)** $651,000.00

**ENGINEERING 10% OF SUBTOTAL (1)** $65,100.00

**SUBTOTAL (2)** $716,100.00

**CONTINGENCY @ 15% OF SUBTOTAL (2)** $107,415.00

**TOTAL CONSTRUCTION COSTS** $823,515.00

**SURVEYING** $15,000.00

**PERMITTING COSTS** $15,000.00

**FINAL PLANS/SPECIFICATIONS** $75,000.00

**TOTAL COST** $928,515.00

Note: All costs associated with Alternative Nos. 1 and 2 are WWDC eligible

6.3 Alternative No.3 – Upgrading of the Existing Distribution System.

Alternative No. 3 would replace the older two and four inch diameter GI and AC mains in the distribution system with six inch diameter PVC pipelines and loop some of the dead end lines.
### TABLE 6.3

**Preliminary Estimate of Level III Costs for Alternative No. 3**

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Estimated Quantity</th>
<th>Unit Price</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobilization</td>
<td>L.S.</td>
<td>1</td>
<td>$30,000.00</td>
<td>$30,000.00</td>
</tr>
<tr>
<td>Replace Two Inch Galvanized Mains with six Inch PVC - Asphalt</td>
<td>L.F.</td>
<td>1,700</td>
<td>$28.00</td>
<td>$47,600.00</td>
</tr>
<tr>
<td>Replace Two Inch Galvanized Mains with Six Inch PVC - Gravel</td>
<td>L.F.</td>
<td>3,150</td>
<td>$20.00</td>
<td>$63,000.00</td>
</tr>
<tr>
<td>Replace Four Inch Transite Pipe with Six-Inch PVC Main</td>
<td>L.F.</td>
<td>780</td>
<td>$28.00</td>
<td>$21,840.00</td>
</tr>
<tr>
<td>Fittings</td>
<td>L.S.</td>
<td>1</td>
<td>$20,000.00</td>
<td>$20,000.00</td>
</tr>
</tbody>
</table>

**SUBTOTAL (1)** $182,440.00

**ENGINEERING 10% OF SUBTOTAL (1)** $18,244.00

**SUBTOTAL (2)** $200,684.00

**CONTINGENCY @ 15% OF SUBTOTAL (2)** $30,102.60

**TOTAL CONSTRUCTION COSTS** $230,786.60

**SURVEYING** $5,000.00

**PERMITTING COSTS** $5,000.00

**FINAL PLANS/SPECIFICATIONS** $30,000.00

**TOTAL COST** $270,786.60

---

### TABLE 6.4

**Preliminary Estimate for Level II Costs**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Video Ten Sleep No. 1</td>
<td>$15,000.00</td>
</tr>
<tr>
<td>Investigations of Easements and Permits</td>
<td>$8,000.00</td>
</tr>
<tr>
<td>Stepped Rate and 7 Day Open Flow Testing of Ten Sleep Well No. 2</td>
<td>$16,000.00</td>
</tr>
<tr>
<td>Additional Engineering to Finalize Designs</td>
<td>$27,000.00</td>
</tr>
<tr>
<td>Surveying</td>
<td>$10,000.00</td>
</tr>
<tr>
<td>Geotechnical Exploration for Tank Siting and Ten inch diameter Transmission Line</td>
<td>$10,000.00</td>
</tr>
<tr>
<td>Hydrant Tests for Flows and Pressures to Calibrate Water System Model</td>
<td>$5,000.00</td>
</tr>
<tr>
<td>Permits</td>
<td>$1,200.00</td>
</tr>
</tbody>
</table>

**TOTAL** $92,200.00
6.4 Preliminary Level II Cost Estimates

Preliminary estimates of Level II costs to further assess Ten Sleep Nos. 1 and 2, to investigate existing easements, and to finalize additional engineering designs are presented in Table 6.4. The WWDC would cover 100% of the Level II costs.
7.0 PERMITTING AND ENVIRONMENTAL ISSUES

For this project to proceed with a Level II investigation, Ten Sleep will be required to obtain certain permits, rights of way, and easements to construct additional water system infrastructure within and near town. State, county, and federal agencies must be contacted and informed regarding the additional Level II work. In some instances, the initial contacts have already been made. The following issues for the alternatives and a potential replacement well must be addressed during final design:

**Easements.** Easements will be required for the transmission and distribution pipelines in addition to the proposed new storage tank. These easements will need to be obtained from private individuals through whose property the pipelines will be passing. The proposed location for the storage tank is currently up for sale at $295,000.00. The owner is Brad Byington, who lives in St. George, Utah. Purchasing an easement would be the recommended option. An easement will also be required for the extension of the transmission line along Highway 434.

**USACE §404 Permit.** The transmission pipeline along Highway 434 to service outlying residents two miles south of the Shriver Subdivision will cross several drainages that would qualify as a Water of the United States due to the presence of a defined bed and bank, and will potentially qualify as a Jurisdictional Wetland. These construction activities may require a §404 permit from the USACE and §401 authorization from the State of Wyoming.

**WDEQ/WQD Permit to Construct.** Each of the three proposed alternatives will require a "Permit to Construct" from the WDEQ/WQD in Cheyenne.

**Water Rights Permit.** Upon completion of a replacement well for Ten Sleep No. 1, the appropriate completion forms must be submitted to the WSEO, and the new water right adjudicated by the State Board of Control. A Statement of Beneficial Use should also be filed with the WSEO. The 1955 water right from Ten Sleep No. 1 can be relocated such that the priority date is maintained. A recent priority date, such as 2002 or 2003, would be attached to any filing for an enlargement on either Ten Sleep No. 1 or 2.

**Environmental Report.** If Ten Sleep intends to pursue funding options offered by the Rural Utilities Service (RUS) and Wyoming Drinking Water State Revolving Fund, the preparation of an Environmental Report (ER) will be required. The ER will need to include, at a minimum, information regarding the purpose of the project, any alternatives to the proposed development, potential impacts to the various environments encountered, and mitigation measures that will be undertaken to reduce overall impacts.
8.0 ECONOMIC ANALYSIS AND ABILITY TO PAY

As explained in Section 5.0, LA recommends Ten Sleep consider adding a 300,000 or 500,000 gallon storage tank, Alternative Nos. 1 and 2, respectively; and replacing the existing two and four inch diameter mains with six inch diameter PVC pipe, Alternative No. 3. Costs associated with the various alternatives presented can be considered separately or combined as follows:

- Alternative No. 1 at a cost of $1,092,399.00
- Alternative No. 2 at a cost of $928,515.00
- Alternative No. 3 at a cost of $230,786.00
- Alternative Nos. 1 and 3 at a cost of $1,323,185.00
- Alternative Nos. 2 and 3 at a cost of $1,159,301.00

There are several potential sources for funding this project. Nearly all of these funding sources may require the installation of meters as part of the project. These funding sources include, but are not necessarily limited to, the following:

- Wyoming Water Development Commission: 50% grant, 50% loan at an interest rate of 6.0%.
- Rural Utilities Service: Of 50% WWDC loan portion; 50% grant, 50% loan at an interest rate of 4.625% for 30 years.
- Wyoming Drinking Water State Revolving Fund: of 50% WWDC loan portion; loan at interest rate of 2.5% for 20 years.
- Wyoming State Loan & Investment Board: 50% grant, 50% loan at an interest rate of 6.0%

### TABLE 8.1
Financing of Transmission Line and Supply Tank
(Alternatives Nos. 1 and 2 – WWDC Funding)

<table>
<thead>
<tr>
<th>Item</th>
<th>Financing Amount Alternative No. 1</th>
<th>Financing Amount Alternative No. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction cost WWDC eligible</td>
<td>$1,092,399.00</td>
<td>$928,515.00</td>
</tr>
<tr>
<td>WWDC 50-percent Grant</td>
<td>$546,199.50</td>
<td>$464,257.50</td>
</tr>
<tr>
<td>Loan Amount</td>
<td>$546,199.50</td>
<td>$464,257.50</td>
</tr>
<tr>
<td>WWDC Loan @ 6.0% - 30 yr.</td>
<td>$3,274.74</td>
<td>$2,783.46</td>
</tr>
<tr>
<td>Totals</td>
<td>($3,274.74)</td>
<td>($2,783.46)</td>
</tr>
<tr>
<td>Total Monthly Cost</td>
<td>($14.49)</td>
<td>($12.32)</td>
</tr>
<tr>
<td>Total Monthly Tap cost @ 226 taps</td>
<td>($14.49)</td>
<td>($12.32)</td>
</tr>
</tbody>
</table>

Note: Total monthly tap costs includes the approximately ten residents from the area south of the Shriver Park subdivision.
Funding from the WWDC can be secured, as shown in Table 8.1, for the water supply and storage portion of the project, or Alternative Nos. 1 and 2. Alternative No. 3 must be financed through another source such as the Wyoming State Loan & Investment Board (SLIB), as presented in Table 8.2. All costs shown below include capital improvements and debt retirement only, and are in addition to current water system costs, including operation and maintenance.

**TABLE 8.2**

**Financing of the Existing System Upgrades**

**(SLIB Funding)**

<table>
<thead>
<tr>
<th>Item</th>
<th>Financing Amount Alternative No. 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction cost SLIB eligible</td>
<td>$230,786.60</td>
</tr>
<tr>
<td>SLIB 50-percent Grant</td>
<td>$115,393.30</td>
</tr>
<tr>
<td>Loan Amount</td>
<td>$115,393.30</td>
</tr>
<tr>
<td>WWDC Loan @ 6.0% - 30 yr.</td>
<td>$691.84</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Total Monthly Cost</strong></td>
<td>($691.84)</td>
</tr>
<tr>
<td><strong>Total Monthly Tap cost @ 226 taps</strong></td>
<td>($3.06)</td>
</tr>
</tbody>
</table>

Note: Total monthly tap costs includes the approximately ten residents from the area south of the Shriver Park subdivision

**TABLE 8.3**

**Financing of the System Upgrades**

**Combine Alternatives No. 1 and No. 3**

**(WWDC and SLIB Funding)**

<table>
<thead>
<tr>
<th>Item</th>
<th>Financing Amount Alternative No. 1</th>
<th>Item</th>
<th>Financing Amount Alternative No. 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction cost WWDC eligible</td>
<td>$1,092,399.00</td>
<td>Construction cost SLIB eligible</td>
<td>$230,786.60</td>
</tr>
<tr>
<td>WWDC 50-percent Grant</td>
<td>$546,199.50</td>
<td>SLIB 50-percent Grant</td>
<td>$115,393.30</td>
</tr>
<tr>
<td>Loan Amount</td>
<td>$546,199.50</td>
<td>Loan Amount</td>
<td>$115,393.30</td>
</tr>
<tr>
<td>WWDC Loan @ 6.0% - 30 yr.</td>
<td>($3,274.74)</td>
<td>SLIB Loan @ 6% - 30 yr.</td>
<td>($691.84)</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td></td>
<td><strong>Totals</strong></td>
<td>($3,966.58)</td>
</tr>
<tr>
<td><strong>Total Monthly Cost</strong></td>
<td></td>
<td><strong>Total Monthly Tap cost @ 226 taps</strong></td>
<td>($17.55)</td>
</tr>
<tr>
<td><strong>Total Monthly Tap cost @ 226 taps</strong></td>
<td>($17.55)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Total monthly tap costs includes the approximately ten residents from the area south of the Shriver Park subdivision.
Funding from the WWDC and SLIB could be combined to finance the upgrades as shown in Tables 8.3 and 8.4. Table 8.3 presents the costs of combining Alternative No. 1, the isolated transmission line and the 500,000 gallon storage tank, and Alternative No. 3, the distribution system improvements. Table 8.4 presents the costs associated with combining Alternative No. 2, the isolated transmission line from Ten Sleep No. 2 and the 300,000 gallon storage tank, and Alternative No. 3, the distribution system improvements. All costs shown below include capital improvements and debt retirement only, and are in addition to current water system costs, including operation and maintenance.

### TABLE 8.4

**Financing of the System Upgrades**

**Combine Alternatives No. 2 and No. 3**

**(WWDC and SLIB Funding)**

<table>
<thead>
<tr>
<th>Item</th>
<th>Financing Amount Alternative No. 2</th>
<th>Item</th>
<th>Financing Amount Alternative No. 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction cost WWDC eligible</td>
<td>$928,515.00</td>
<td>Construction cost SLIB eligible</td>
<td>$230,786.60</td>
</tr>
<tr>
<td>WWDC 50-percent Grant</td>
<td>$464,257.50</td>
<td>SLIB 50-percent Grant</td>
<td>$115,393.30</td>
</tr>
<tr>
<td>Loan Amount</td>
<td>$464,257.50</td>
<td>Loan Amount</td>
<td>$115,393.30</td>
</tr>
<tr>
<td>WWDC Loan @ 6.0% - 30 yr.</td>
<td>($2,783.46)</td>
<td>SLIB Loan @ 6% - 30 yr.</td>
<td>($691.84)</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>($3,475.30)</strong></td>
<td><strong>Totals</strong></td>
<td><strong>($15.38)</strong></td>
</tr>
<tr>
<td>Total Monthly Cost</td>
<td></td>
<td></td>
<td><strong>($3,475.30)</strong></td>
</tr>
<tr>
<td>Total Monthly Tap cost @ 226 taps</td>
<td></td>
<td></td>
<td><strong>($15.38)</strong></td>
</tr>
</tbody>
</table>

Note: Total monthly tap costs includes the approximately ten residents from the area south of the Shriver Park subdivision.
9.0 RECOMMENDATIONS

To meet the current and future water demands of Ten Sleep, LA recommends Ten Sleep request WWDC funding of a Level II investigation to finalize the design engineering for the selected alternative. DEQ/WQD is responsible for safeguarding public water supplies in the state and therefore any new construction or modifications must be permitted by WQD prior to construction. The following list provides more detailed recommendations for the supply, transmission, distribution, storage, and operation of the Ten Sleep water system:

**Water Supply**

- Clean the well house of Ten Sleep No. 1 and remove unnecessary materials to reduce the possibility of contamination from any source in the immediate vicinity of the wellhead.
- Conduct a downhole video survey of Ten Sleep No. 1 to assess the current condition of this well following recent wellhead work. Results of the video should be used to plan for the eventual replacement of this well.
- Continue to record meter readings on a weekly basis.
- Record wellhead pressures monthly to extend the record of seasonal and long-term changes in artesian pressure. Plot records to assess these variations. These measurements will also yield valuable information regarding the current status of Ten Sleep No. 1 and its apparent interconnection of Madison and Tensleep Aquifers.
- Utilize the pressure reducing valves on Ten Sleep Nos. 1 and 2 to place primary water system demand on Ten Sleep No. 2, the town's highest yielding, most efficient well.
- Conduct open flow, stepped rate aquifer testing of each well once every three years to assess well conditions and aquifer performance.
- Request or file for enlargement of water rights on Ten Sleep Nos. 1 and 2 to ensure the town has adequate supply for future growth beyond the planning horizon.
- Reconfigure wellhead transmission lines such that the flowmeters are installed according to manufacturer's specifications, particularly at Ten Sleep No. 1.

**Transmission & Distribution**

- Replace the two inch diameter galvanized iron and four inch diameter AC mains with six inch diameter PVC mains.
- Record distribution system line pressures weekly to assess whether any unreported leaks have developed.
- Install a check valve on both supply lines in the well houses to prevent backflow into the well.
- Verify that all residents in the service area or points outside who have water service taps and any domestic wells do not commingle water between these systems. At a minimum, backflow preventors should be installed at these points.
Investigate backflow prevention for the sprinkler at the cemetery, and if necessary, install a backflow preventor.

Purchase and install flowmeters for taps to meter usage.

Clean valve boxes of debris using valve box clean out tools or alternate methods, and install operating nut extension rods. The extension rods would allow valve operation if the valve boxes were damaged. Replace all damaged valves and exercise all valves on a regular basis.

Install detectable marker tape over the waterline when any section or part of the waterline is excavated to accurately locate existing lines. With a magnetic locator, the waterlines will then be locatable within two feet.

**Storage**

Consider a water storage tank to provide adequate volume for fire fighting requirements and to counteract the fluctuations in demand at peak times. This will also provide flows to allow additional users to come on line.

If a storage tank is installed it is recommended that the PRV’s be removed as this will not be needed to supply water to the tank.

With storage a chlorine facility will need to be installed as per WDEQ requirements.

**Operation**

Consider modifying billing rate structure such that residents pay according to usage.

Establish a fire hydrant flushing program at a minimum of once per year for each hydrant. This will help prevent biofilm from building on iron pipes that produce bacteria buildup.

Exercise all gate valves within the distribution system at least once a year. This will help to get to know where all the valves are especially those in gravel roads, as these tend to get lost during the winter when snow plowing buries them and they are not relocated after the snow melt.

Establish a good record keeping protocol for all testing done, meter records, disinfection testing results, dates of hydrant flushing, valve exercising, etc.

A representative from the Town should attend the American Water Works Association Annual Meeting/Convention at least once every three to four years. The classes and seminars are the best available and will keep staff abreast of the changes in technologies and useful products as well as Federal Rules and Regulations regarding the Safe Drinking Water Act, etc.

Train a second/backup licensed operator to assist in running the system.

Consider instituting a water conservation program to reduce water demands. A public awareness program for such a program typically addresses issues such as leak detection (taps, toilets, etc.), hydrant flow restrictors (showers), and lawn watering.
10.0 REFERENCES


Fox, J.E., and Dolton, G.L., 1995, Wind River Basin Province and Bighorn Basin Province, USGS National Oil and Gas Assessment
