Groundwater Technical Memorandum No. 1
2015 Laramie Master Plan, Level I – Appendix 410

TO: Wyoming Water Development Commission — Date: November 30, 2015
City of Laramie
WWC Engineering

FROM: Chris Moody, P.G. – Wyoming Groundwater CM
Bern Hinckley, P.G. – Hinckley Consulting

HISTORY OF GROUNDWATER DEVELOPMENT AND USE

This technical memorandum is the first of a series of four regarding the groundwater supply of the City of Laramie. Companion memoranda address the hydrogeology of the Casper Aquifer, water quality and related City programs to protect and monitor the Casper Aquifer, and recommendations for aquifer management and future use. Water rights pertaining to the administration and limitations of groundwater use by the City are discussed in Appendix 400.

Tables and figures are provided in sequential order at the end of each memorandum. In addition to the tables and figures, Plate I is a comprehensive geologic map of the Laramie area that identifies the location of wellfields, wells, and hydrogeologic features discussed in the memoranda. References cited in the technical memoranda are listed in the "References" chapter of the main report.

This technical memorandum describes the historical development and use of groundwater as a municipal water supply by the City of Laramie. Topics given cursory attention in this memorandum are revisited in Technical Memoranda Nos. 2, 3, and 4. This discussion is an update of the 2006 Laramie Water Management Plan, (WWC Engineering, 2006) and earlier work by Huntoon and Lundy (1979b).

I. Water Supply Development History

The City of Laramie was founded in 1868 based on a plentiful supply of groundwater from City Springs for Union Pacific Railroad (UPRR) locomotives and the new town. Combined with Pope Springs and Solider Spring to the south, the City had a substantial initial supply of water for municipal purposes. Since 1868, the development of the City water supply has occurred in four phases culminating in the current configuration of obtaining water from the Laramie River and the Casper Aquifer. Figure TM 1-1 shows the location of surface water diversions on the Laramie River, the surface water treatment plant, and the wellfields that extract groundwater from the Casper Aquifer.

The first phase of municipal water development, from 1868 to 1940, relied on the natural discharge from three springs that discharge groundwater from the Casper Aquifer: City

Springs, Pope Springs, and Soldier Spring. Five miles of 12-/14-/16-inch pipeline was installed in 1923 to convey (and still does) water via gravity flow from Pope Springs and Soldier Spring to Laramie which lies at a lower elevation than these springs. Throughout the 1920s and 1930s, the City tried to coax more water out of the aquifer by lowering the headworks at Pope and Soldier Spring, but the increased flow from the springs was relatively small and temporary. As Laramie's population grew and the drought in the 1930s reduced aquifer discharge at the springs, the limitation of using only the natural discharge from the springs became a problem. In 1937-39, the City installed three production wells at Pope Springs and began to use the "reservoir" storage capacity of the Casper Aquifer.

The second phase, from 1940 to 1981, involved the acquisition and use of surface water rights on the Laramie River. In 1940, the City purchased water rights from the Dowlin Ditch, thus sharing the first priority on the Laramie River. In 1945, the City proceeded with a water right transfer of 10 cubic feet per second (cfs) from the Dowlin Ditch to the Pioneer Canal for municipal use. In 1947, the City constructed a 20-inch pipeline from Sodergreen Reservoir to convey raw water to the City. At that time, water from the Laramie River was used for railroad purposes, lawn irrigation at the cemetery, and on the University of Wyoming campus. By 1953, municipal demands had increased to the extent that the City decided to treat Laramie River water for municipal use and constructed a water treatment plant on the west side of the railroad tracks at the intersection of Garfield and Pine Streets.

In 1963, the City again petitioned the Board of Control to transfer additional Dowlin Ditch water rights to municipal use and obtained the right to divert another 4.31 cfs. With the 1964 transfer, the City has the right to divert 14.31 cfs (9.25 million gallons per day - mgd) from the Laramie River at the Pioneer Canal headgate. The City then constructed a water treatment plant located 1.6 miles east of Sodergreen Reservoir with a rated capacity of 6.0 mgd and installed 17 miles of 24-inch pipeline to convey treated river water to the City.

In 1981, the City purchased the Monolith Ranch and its associated water rights, including an additional portion of the Dowlin Ditch right amounting to 20.1 cfs. Irrigation water rights associated with the 1981 purchase have not yet been transferred to municipal purposes. With the acquisition and transfer of Laramie River water rights and the construction of surface water infrastructure, the City had developed a conjunctive surface water and groundwater supply system.

The third phase, from 1982 to 2000, involved the construction of additional infrastructure to extract groundwater from the Casper Aquifer. In 1981, the City drilled a fourth production well at the Pope Wellfield and installed two production wells at City Springs (Turner Wellfield). These three wells were put in service in 1982. In 1998, the City installed a production well at Soldier Spring. In 2000, the Spur Wellfield was developed with the installation of two production wells and approximately 6 miles of 14- and 18-inch pipeline to convey groundwater from the wellfield to the north end of the City's distribution system. Development of the Turner, Pope, Soldier, and Spur wellfields allows the City to extract groundwater as needed to meet base and peak demands and provides the opportunity to use the reservoir storage characteristics of the Casper Aquifer.

The fourth phase, from 1995 to the present, involves year-round operation of the surface water treatment plant and the development of an operational strategy for the surface water and groundwater supply. Low demand periods in the fall-winter-spring are satisfied by the surface water treatment plant and artesian flow from Soldier Spring. As demands increase in the late-spring and summer, the Turner, Pope, and Spur wellfields are operated as needed to satisfy demand.

The conjunctive surface water and groundwater supply system provides the City considerable supply capacity and operational flexibility to meet demands. With a well-developed groundwater extraction system in place, the challenge going forward is to use the groundwater resource to best economic, regulatory, and operational advantage.

II. Wellfield History, Characteristics, and Use

This section describes the basic characteristics of each wellfield and serves as background information for Technical Memoranda Nos. 2 - 4. Figures TM 1-2 through TM 1-5 and Plate I illustrate the location of production wells and pertinent features at each wellfield. Table TM 1-1 and Table TM 1-2 list the current production characteristics of each production well and wellfield.

Each wellfield is discussed in the order of use or activation during a calendar year as demands fluctuate. In most instances, the order of wellfield activation to supplement surface water treatment plant production is as follows:

- Low demands during late fall, winter, and early spring are met using artesian production from Soldier Spring (Soldier No. 1 well);
- Moderate demands during spring, summer, and fall are met using the Turner Wellfield in conjunction with artesian flow from Soldier Spring; and
- High demands during the summer are met using the Pope Wellfield followed by the Spur Wellfield in conjunction with the Turner Wellfield and Soldier Spring.

Annual wellfield production is summarized by an annual volume such as million gallons (mg) per year. System operators reduce this annual volume to an average daily rate, mgd, which is also used to describe production over short time periods such a month, week, or day. Many historical documents use mgd to describe instantaneous and annual spring discharge and average wellfield production. In these discussions of wellfield production, mgd will be used to describe average groundwater production rates over a specified time period.

Soldier-Pope Wellfield

The operation and production capabilities of the Soldier and Pope wells must be considered together. Although the Soldier and Pope wells are located 1.4 miles apart, these two wellfields are intimately connected by hydraulic pathways in the aquifer and a common transmission pipeline. Important aspects of the current operation and production from the Soldier and Pope wellfields are dictated by the hydraulic relationship between Soldier Spring and Pope. In concept and operation, the Soldier and Pope wellfields should be thought of as a single wellfield (Soldier-Pope) with a long intra-wellfield pipeline.

Morgan (1947) was the first to recognize that discharge at Soldier Spring was affected by pumping the Pope wells. There are multiple lines of evidence of the excellent hydraulic connection between Pope and Soldier with the most contemporary evidence being a pump test conducted in 1993 whereby the Pope No. 3 and No. 4 wells were pumped at a combined rate of 2,950 gpm for 5 days (WWC, 1995). Drawdown at a monitor well (Soldier MW-1) located approximately 500 feet north of Soldier Spring began 40 minutes after the start of pumping the Pope wells. Operationally, the artesian flow from production well Soldier No. 1 declines when the Pope wells are operating (Scott Palm, pers. comm., 6/25/15).

Soldier Spring has been a source of municipal water since as early as 1915 at which time the spring flow was shared between the City and the State fish hatchery. In 1924, the hatchery moved to Red Buttes and the entire flow of the spring became available to the City. Prior to development of the Pope Wellfield in 1937, the sustained discharge from Soldier Spring was approximately 1.55 mgd (Morgan, 1947).

In 1937, the City dug a 10-foot diameter by 21 feet deep cistern (a.k.a. Forney Shaft) just west of the original spring (Plate I and Figure TM 1-2). The cistern penetrated 8 feet of the Satanka Shale and 13 feet of the uppermost limestone and sandstone of the Casper Formation. A pump was installed in the cistern to allow additional production and to counteract pipeline pressure caused by pumping the Pope wells. Buried lateral drain pipes north of the cistern collected and discharged near-surface groundwater into the transmission pipeline that exited the cistern and conveyed water to the Wye where the Soldier and Pope transmission lines meet. Average production from the cistern from 1989 to 1998 was 1.4 mgd. Due to water quality concerns (see Technical Memorandum No. 3) and limited operational flexibility, the City plugged the cistern in 1998 and replaced it with a production well.

In 1993-95, five monitor wells were completed in the Casper Aquifer on City-owned property at Soldier Spring (Figure TM 1-2). The monitor wells have been used for water quality and water-level monitoring.

In 1998, the Soldier No. 1 production well was installed 450 feet west of the cistern (Plate I and Figure TM 1-2) and was put in-service in 1999. The well has exceptional production characteristics as illustrated by a specific capacity value of 191 gallons per minute per foot of drawdown (gpm/ft) as listed in Table TM 1-1. Soldier No. 1 is equipped with a variable frequency drive controlled pump that allows variable pumping rates. The outlet works at the wellhead are in a vault below ground surface such that groundwater flows out of the well and into the pipeline under artesian pressure.

Soldier No. 1 is operated primarily under non-pumping, passive artesian flow conditions. Artesian flow from Soldier No. 1 discharges into a pipeline (invert elevation 7311 feet) and flows by gravity to Laramie and into the low-level reservoir (elevation 7248 feet) at the City Springs enclosure (Plate I). The pipeline and well is “choked back” by pipeline valves to provide 10 to 15 psi of backpressure in the pipeline that prevents water treatment pumps at the Wye from “air-locking”. Consequently, artesian production from Soldier No. 1 is slightly less than the unrestricted artesian flow. Currently, the “choked” artesian flow is approximately 1.8 mgd, and if not choked back, the artesian flow would be approximately 2.0 mgd (Scott Palm, pers. comm., 6/23/15). During dry years, artesian production from Soldier No. 1 is approximately 1.5 mgd (Mike Lytle, pers. comm., 8/8/15).

Artesian flow from Soldier No. 1 is a constant, reliable, and inexpensive source of water. Water from the surface water treatment plant and artesian flow from Soldier No. 1 satisfy municipal demands from October through April. The pump in Soldier No. 1 is rarely used because of concerns with the slow recovery of artesian flow from Soldier No. 1 after the termination of pumping (Mike Lytle, pers comm., 2/4/15). Consequently, the combination of pumping Soldier No. 1 with either of the higher yield Pope No. 3 or No. 4 wells is used only during extreme demand and unusual system conditions.

Historical artesian flow production data indicate that current artesian flow from Soldier No. 1 is the same as, or slightly higher than, rates documented during early development of the spring in the 1940s. From 1999 to 2014, total monthly and annual production records indicate that average daily production from Soldier No. 1 varied from 1.5 to 2.1 mgd with an average of 1.8 mgd. These values are a reasonable approximation of natural artesian flow because use of the pump was rare. During the same time period, average daily production from the Pope Wellfield was 0.13 mgd such that the combined average daily production from Soldier and Pope was approximately 1.9 mgd. This value is identical to the combined average daily production of 1.94 mgd from Soldier and Pope during 1941 to 1943 (Morgan, 1947).

The headwater of Soldier Creek is approximately 240 feet north of Soldier No. 1 and consists of a perennial wet area with surface water flowing off-site to the west (Plate I and Figure TM 1-2). The source of surface water is groundwater from the Casper Aquifer that flows vertically through fractures in the lower-most part of the overlying Satanka Shale. Despite the extraction of groundwater from the Casper at Soldier No. 1 by either artesian flow or by pumping, groundwater continues to flow upward to the surface at the spring. Pumping Soldier No. 1 reduces the volume of groundwater that discharges to the surface but does not completely dry up the wet area (Scott Palm, pers. comm., 6/23/15). The groundwater system at Soldier Spring could be further evaluated by the quantification of off-site flow during artesian and pumping operation of Soldier No. 1 to directly assess/quantify surface-flow suppression or elimination.

Pope Springs is located 2.8 miles south of Laramie, 1.4 miles north of Soldier Spring, and was first used for municipal purposes in 1920. At that time, discharge from Pope Springs was approximately 0.9 mgd (Morgan, 1947). In 1934, Pope Springs went dry due to drought and the lowering of headworks at Soldier Spring in 1929 and 1932 (Beckwith, 1937). Efforts by the City in the 1930s to reestablish adequate discharge from Pope Springs were unsuccessful and discharge from the original spring location has not occurred since.

In 1937-39, the City installed three production wells - Pope No. 1, Pope No. 2, and Pope No. 3 – located approximately 1,100 feet west of the springs and within a 6.4 acre parcel of City-owned property (Plate I and Figure TM 1-3). In 1982, Pope No. 4 was installed as a high capacity well to help meet seasonal high demand.

Production characteristics of the Pope wells are excellent as illustrated by specific capacity values ranging from 40 to 125 gpm/ft (Table TM 1-1). Although Pope Springs began as a spring-fed municipal supply, it is now a conventional wellfield that extracts groundwater from aquifer storage rather than capturing spring discharge.

Currently, the Pope wells are rarely used because the water supply gain by pumping the wells is rather small given the commensurate gradual decline of artesian flow from Soldier No. 1. Typically, the Pope No. 1 and No. 2 are used when the artesian flow of Soldier No. 1 is insufficient. Pope No. 1 and No. 2 are usually operated together and provide a relatively small boost in overall water production. Production from these two wells does not compete for pipeline capacity with Soldier No. 1 flow. If water demand requires pumping Soldier No. 1, Pope production is shifted to the solo operation of the higher-yield Pope No. 3 or Pope No. 4 wells.

Regardless of the hydraulic interaction, the Pope wells provide supply redundancy during emergency conditions and supplement the overall supply to some degree during periods of extremely high demand.

Water from Soldier No. 1 flows northward to the Wye, where water from the Pope wells is commingled with Soldier water into a common pipeline that conveys water to the City storage and distribution system (Figure TM 1-1). These pipelines were installed in 1923, are constructed of cast iron with lead joints, and have a pressure rating of 100 feet (43 psi) as indicated by a pipe manufacturer (Clow, 1967). Given the pipeline age and materials, there is uncertainty regarding pipeline pressure tolerances and flow capacity. The pipeline is typically operated at a maximum pressure of 43 psi which limits production from the combined Soldier and Pope system to approximately 4.5 mgd (Mike Lytle, pers. comm. 7/8/15). However, production from the Soldier-Pope wellfield will occasionally exceed 4.5 mgd as occurred in the summer of 2002 when monthly production on a daily basis was approximately 4.9 mgd (Table TM 1-4). The City has not conducted a pressure test of the pipeline. Basically, the wellfields are operated at production rates and pressures known to not cause problems to the pipeline.

Based on historical records, the long-term average combined annual production from the Soldier-Pope wellfield is 693 million gallons (1.9 mgd) with the vast majority of the production derived from artesian flow from Soldier.

Turner Wellfield (City Springs)

Laramie was founded and built around the groundwater that discharges from City Springs. From 1868 to 1982, the City relied on some or all of the groundwater that discharged from City Springs. The primary discharge point is a spring (City Spring) located in the cluster of cottonwood trees at the east end of the enclosure (Plate I and Figure TM 1-4). Although most of the groundwater discharges at the spring, a substantial amount seeps upward through the Satanka Shale to the ground surface in the area west of the spring. In the 1930s, a shallow clay pipe and springbox system buried 4 to 5 feet below grade was installed to help keep the enclosure area dry and to reduce the exposure of groundwater to near-surface contaminants. In the past, groundwater collected at the spring and by the pipe-springbox system discharged into the 1.4 million gallon reservoir (abandoned) for City use. Currently, groundwater collected by this system discharges directly into Spring Creek from an outlet pipe located east of the covered 8 million gallon low-level reservoir (Figure TM 1-4). Unfortunately, without assistance from pumping the Turner wells, the pipe-springbox collection system cannot always eliminate the discharge of groundwater at the spring and at low-lying areas within the enclosure.

In 1982, the Turner No. 1 and Turner No. 2 production wells began to intercept groundwater before it discharges to the surface and to pump groundwater from aquifer storage as needed in response to demand. Turner No. 2 is located in the enclosure west of the spring and when not pumping, the well will often flow, especially in the late-winter and early-spring. Turner No. 2 serves as an additional “spring” collection point that helps keep the enclosure area dry. In the spring of 2015, artesian flow from Turner No. 2 was approximately 0.3 mgd. Turner No. 1 is located on the south side of Garfield Street, outside the enclosure and southwest of City Spring. Turner No. 1 rarely experiences artesian flow due to its higher ground elevation relative to the ground elevation at City Spring.

Operationally, the Turner Wellfield is the next-in-line to supplement the water supply when demand exceeds the amount of water that can be provided by combined production from the surface water treatment plant and by artesian flow from Soldier No. 1.

Production characteristics of the Turner wells are good, as demonstrated by specific capacity values from 36 to 66 gpm/ft (Table TM 1-1); however, these specific capacity values are noticeably lower than many of the other municipal wells. Regardless, the Turner wells are pumped at relatively high rates (i.e. 1,700 to 2,200 gpm). When the Turner wells are repeatedly operated simultaneously for 2 to 3 weeks, aquifer recovery mechanics (see Technical Memorandum No. 2) will reduce the pump run-times for subsequent pumping periods.

When either or both of the Turner wells are operating, the head in the Casper Aquifer is lowered below the elevation of the spring and the pipe-springbox collection system. In contrast to Soldier Spring, the Turner well(s) can capture all of the spring-related discharge in the enclosure. Turner No. 2 will eliminate flow from the outlet pipe after 3 to 4 days of pumping, and the simultaneous operation of Turner No. 1 and Turner No. 2 will eliminate flow from the outlet pipe in 1 to 2 days. When the Turner wells are shut off, the head in the Casper Aquifer recovers and flow from the outlet pipe will eventually resume and gradually increase with time. When the Turner wells are off for an extended period, discharge from the outlet pipe returns to a rate commensurate with hydraulic conditions in the aquifer.

In 2007, the City installed a flowmeter in the outlet pipe. The collection of “overflow” data allows the measurement of the total outflow from City Springs, i.e. well production plus overflow. Complete overflow data for the years 2007, 2008, 2009, 2012, and 2013 allow the calculation of total annual discharge from City Springs during these years. Annual discharge, on an average daily basis, for these years varied from 1.47 to 1.63 mgd.

Production records indicate that these recent annual discharge values, as expressed by mgd values, are similar to long-term historical values of discharge from City Springs. From 1941 to 1943, the discharge rate from City Springs varied from 1.60 to 1.70 mgd with an average sustained flow of 1.65 mgd (Morgan, 1947). City production records from 1967 to 1981 (i.e. prior to Turner wellfield development) indicate minimum and maximum discharge rates from City Springs of 1.15 and 2.26 mgd, respectively, with a mean discharge rate over that period of 1.64 mgd (WWC, 1996a). Discharge measurements in May 1993 and November 1995 indicated rates of 1.56 and 1.21 mgd, respectively (WWC, 1996a). The natural discharge rate from City Springs has a recorded minimum of 1.2 mgd, a maximum of 2.3 mgd, and an average of 1.6 mgd. Historical pumping of the Turner Wellfield has not “mined the aquifer” nor has it reduced the amount of annual discharge.

Spur Wellfield

The Spur Wellfield is located 5.6 miles north of Laramie and consists of two production wells, Spur No. 1 and Spur No. 2, drilled in 1997 and put in-service in 2000. The Spur wells are phenomenally productive with specific capacities ranging from 440 to 580 gpm/ft. The allowable combined maximum production from these two wells is 4.0 mgd. Pumping run-time is not constrained by drawdown in the production wells, so these wells can be operated simultaneously as needed. Instantaneous and annual wellfield production, however, is limited by agreement and by infrastructure capacity. In contrast to the other wellfields, there is no historical or existing spring in the vicinity of the Spur Wellfield.

As part of the groundwater exploration program at the Spur in 1997, twelve monitor wells, MW-1 to MW-12, were installed in the vicinity of the Spur production wells (Plate I and Figure TM 1-5). The monitor wells were used to evaluate the hydrogeology of the Casper Aquifer in the Spur area and selected monitoring wells are currently used for long-term monitoring of aquifer water levels and water quality.

The Spur Wellfield is typically used as a peak supply when the other wellfields are not able to keep up with demand during the summer months. The Spur wells pump directly into the high-level reservoir, denying the wells modulation by the higher-volume low-level reservoir and thereby the wells require more frequent pump cycling.

An additional operational consideration is that production from Spur No. 1 generates a financial obligation to the State of Wyoming (land owner), amounting to $15 per acre-foot of water produced. Thus, if only one well is needed, there may be a financial incentive to use Spur No. 2 which is on private land. Due to its location further west, Spur No. 2 will generate slightly less drawdown at the monitor wells and therefore there may be a slight operational advantage to using Spur No. 2 in preference to Spur No. 1.

Technical Memorandum No. 2 provides an updated and detailed analysis of the response of aquifer water levels to Spur Wellfield production and to aquifer recharge that may modify or expand future use of the wellfield.

<u>Spur Wellfield Use Agreement</u>. Unlike for other City wellfields, the City entered into an agreement with local water well owners in the Spur area that defines maximum annual volumes and maximum daily rates for withdrawals from the Spur Wellfield based on the depths to water in five specified monitoring wells. The agreement was signed in March 1998 and wellfield production began in 2000. Table TM 1-3 summarizes the terms of the agreement and a copy of the agreement is provided as Attachment 1.

Figure TM 2-8 shows that the August 22, 1997 baseline values for the agreement were measured at the highest water level of the period of record for this well. There is no discrimination between City-production induced drawdown in the compliance monitor wells and water level declines simply due to natural fluctuations. Due to the lack of data on drawdown relationships in this area at the time the agreement was developed, and the chance selection of particularly high water levels to set the compliance baselines, City production is subject to curtailment regardless of any established connection between City production and monitor well long-term depths to water. Figure TM 2-8 demonstrates that the water level in MW-7 nearly hit the first production-curtailment trigger in 2009, despite minimal City production for the preceding 6 years.

2002 production was basically at the agreement production caps, both for annual total volume and for peak daily production rate. For example, the July 2002 production averaged approximately 4 mgd. While the aquifer largely recovered from this production on an annual basis (assuming much of the 2002 vs 2003 difference was the result of a long-term trend) the summer spike came within 6 feet of triggering a short-term curtailment of the pumping rate. Had this spike occurred in a year of overall lower water levels (e.g. 2009) the depth to water in MW-7 would have forced the production rate down to 2.0 mgd per the third compliance bracket of "25-30 feet" listed in Table TM 1-3.

As of July 1, 2015, the water level elevations in MW-7, MW-8, MW-10, and MW-11 are 3.4 to 4.5 feet below the August 22, 1997 baseline values. In contrast, the water level elevation in MW-12 is 3.1 feet above the 1997 baseline value.

Based on the terms of the agreement, compliance would be more easily assured by switching Spur Wellfield management away from a summer-peaking approach to lower production rates for longer periods of time, particularly in years of relatively low overall aquifer water levels. To minimize monitor well drawdown, the City should use Spur No. 2, the farthest west of the two Spur wells, as often as possible when both wells do not need to be operated simultaneously.

Fortunately, the agreement includes provision for changing the terms of the agreement after twenty years of wellfield operation, i.e. in 2020[1]. We strongly recommend a thorough review of the agreement in light of subsequent experience, including:

- Revision of either the baseline water levels used to define "drawdown" or development of trigger-points that distinguish natural from wellfield production-induced impacts on monitor well water levels.

- Revision of production peak rates to reflect the points at which short-term drawdown impacts have a significant impact on domestic wells. This should include examination of individual domestic well completion details (e.g. depth, saturated thickness, pump setting as tabulated in Appendix F in Volume II of the WWC, 1997c report on the Spur Wellfield) with respect to Wyoming State Engineer's Office criteria. The North Cheyenne area provides a precedent for SEO requirement of minimum depths for domestic wells to reduce the incidence of inter-well interference.

It appears likely that the flexibility of operation that this large groundwater reservoir allows could be substantially increased without significant impact on neighboring domestic wells.

III. Water Year 2002

In 2002, the Laramie area experienced the driest year of the historical record. Total precipitation in 2002 at the Laramie Airport was 5.40 inches whereas the average annual precipitation at the airport is 10.74 inches. That summer the Laramie River was dry at the City headgate downstream of Woods Landing and during the months of July and August the surface water treatment plant produced only 10.3 million gallons (0.16 mgd).

[1] Article 12: "Twenty years after beginning production, the City may elect to petition the State Engineer's Office to modify the monitoring program and other appropriate conditions of the permit, based upon the twenty years of data related thereto. The State Engineer will provide an adequate public notice and comment period…"

Thus, the direct flow of the Laramie River and the associated minor storage at Sodergreen Reservoir were unavailable and groundwater became the sole source of water available to meet the high summer demand. The reduction in annual surface water production as a result of low river flows in 2002 can be seen in Figure TM 1-6.

With a large instantaneous production capacity from the wells and large aquifer reservoir capacity, the groundwater supply system was able to meet 2002 summer demands and avoid water use restrictions despite extreme conditions. Hydrologic conditions and water system performance in 2002 demonstrates the "robustness" of Laramie's groundwater supply system and the flexibility to meet demands afforded by a conjunctive surface water and groundwater supply system.

Monthly groundwater production during the summer of 2002 provides an empirical benchmark for defining highly reliable 1-month and 3-month summer production capabilities of the groundwater system. Table TM 1-4 lists maximum measured production for 1-month and 3-month periods for each wellfield in 2002. Weekly and daily production at each wellfield during the summer of 2002 was not analyzed, so the 1-week and peak day values are conservatively adopted from the 1-month value.

The peak day values listed in Table TM 1-4 are considered to be highly reliable because the infrastructure and aquifer actually demonstrated the ability to provide these rates under the most extreme conditions on record. Consequently, the peak day, 1-week, 1-month, and 3-month mgd values are very conservative. Under most circumstances, wellfield production capability over these time periods will be higher. Regardless, these conservative mgd values are used for water planning purposes.

IV. Water Supply Production – 1999 to 2014

Figure TM 1-6 is a graph of annual production from surface water and groundwater from 1999 through 2014. The graph illustrates a significant decline in water production (demand) in 2003 that has persisted through 2014. Ignoring 2002 when the Laramie River was dry at the headgate that summer, annual production from the surface water treatment plant has been fairly constant at approximately 948 mg. Average annual groundwater production from 2003 to 2014 was 961 mg which is a decline of approximately 25% from the 1999 to 2001 average of 1,281 mg. Groundwater currently provides approximately 51% of the total water supply, compared to 56% during 1999 to 2002, which reflects the slight shift towards surface water production.

V. Wellfield Production – 1992 to 2014

Figure TM 1-7 is a graph that illustrates the annual production from each wellfield during 1992 to 2014. One can clearly see that the Spur Wellfield is rarely used and use of the Pope wells has declined significantly since Soldier No. 1 was brought on-line in 1999. Since 1999, production from Soldier No. 1 has been consistent at 1.8 mgd (i.e. historical average from Soldier Spring) because of the primary use of artesian flow from the well. Production variations above or below this average value from Soldier No. 1 are probably a response to hydraulic conditions in the aquifer (i.e. increased recharge during 2009 to 2012). From 1992 to 2014, average annual production from the Turner Wellfield was 1.0 mgd, and since 2003 the average annual Turner Wellfield production has declined to approximately 0.74 mgd. Over the last 23 years, and especially over the last 12 years, production from the Turner Wellfield has been significantly less than the natural discharge of City Springs of approximately 1.6 mgd.

Since the decline in demand in 2003 and slight reduction in groundwater use, the average annual production of groundwater has been noticeably less than the historical total annual combined discharge of groundwater at City Springs and Soldier-Pope springs. Morgan (1947) documented a total combined annual average discharge of approximately 3.5 mgd from City Springs (1.6 mgd) and Soldier-Pope (1.9 mgd). This 3.5 mgd value has been verified many times by direct measurement of spring discharge during both pre- and post-wellfield development periods. Since 2003, the average annual wellfield production has been approximately 961 mg or, on an average daily basis, 2.6 mgd. Over the last 12 years, annual wellfield production (including Spur) has been approximately 0.9 mgd less than the historical combined annual discharge from the springs. Clearly, the groundwater resource is not being stressed by City wellfield withdrawals.

Since operation of the Turner Wellfield began in 1983, the annual production rate on an average annual daily basis from the Turner wells has varied from 0.53 to 1.97 mgd with an average rate of 1.06 mgd. In only 4 of the last 31 years have the Turner wells produced annually the volume of groundwater that equals or exceeds the historical average annual discharge of 1.6 mgd at City Springs. In general, when annual Turner Wellfield production exceeds 1.6 mgd, there will be little or no discharge from City Springs during that particular year. When annual production is less than 1.6 mgd, flow from City Springs (i.e. overflow from buried collection system) will occur following termination of pumping the Turner wells.

The importance of the Soldier Spring supply cannot be over emphasized. From 2003 to 2014, the artesian flow from Soldier No. 1 has comprised 69% of the annual groundwater production and 35% of the total annual water supply production by the City. The artesian flow from Soldier Spring is fully utilized because of the design of Soldier No. 1 which captures and discharges the majority of the artesian flow into the gravity pipeline that conveys water to Laramie. Water from Soldier Spring is cheap and easy, and the annual production is consistent at approximately 1.8 mgd. Pumping Soldier No. 1 is rarely required and only during periods of extremely high demand or system emergency.

The two wellfields not associated with a spring, Spur and Pope, are used only during high demand periods in the summer when combined production from the surface water treatment plant, Soldier No. 1, and the Turner Wellfield cannot keep up with demand. Spur and Pope, however, were critical supply sources during the summer of 2002.

VI. Groundwater Use Strategies

Over the past 30 years, there have been changes in the development of the water supply that have expanded the potential use of groundwater while reducing its actual use. Prior to 1995, the surface water treatment plant (SWTP) was operated from May to October and surface water served as a peaking supply for the high demand summer months. Groundwater from the wellfields was used as the base supply year-round and to supplement summer-time peaking.

In 1995, the SWTP was modified to allow year round operation. The surface water and groundwater operational strategy was modified such that the SWTP provides a base winter (November – April) supply of approximately 1.5 mgd supplemented by the 1.8 mgd artesian flow from Soldier No. 1. As demands and surface water supplies increase during May – October, SWTP production increases to about 6 mgd and the Turner, Soldier-Pope, and Spur wells (in that order) are pumped as needed to meet peak demands.

Based on operational observations in the early 1990s that the aquifer and production wells were not recovering as quickly after extended periods of pumping as they had in the 1980s, it was postulated that the wellfields were being pumped too hard. Under the new operational strategy in 1995, the wells were not pumped during the winter and the aquifer was allowed an extended period of time to recover. The gradual rise in water levels at the Huntoon No. 1 and Huntoon No. 2 monitor wells that occurred after 1995 suggested that the aquifer was responding positively to this operational strategy.

In hind-sight, the reduction in pumping run times was likely due to the combination of drought/low recharge during the early 1990s and the gradual bleeding off of high head for the 9 years following the “once in a lifetime” recharge event in 1983-84. The outstanding wellfield behavior (i.e. higher than expected pumping rates and rapid water level recovery) during the latter half of the 1980s was due to relatively high head in the aquifer following the 1983-84 recharge event. A detailed discussion of the 1983-84 recharge event is presented in Technical Memorandum No. 2, which further explains that the water level rise in the Huntoon wells after 1995 reflected an overall increase in aquifer recharge during that time period rather than being the result of reduced wellfield production.

The current groundwater management strategy is to keep the Casper Aquifer as full as possible to serve as a “savings account” that can be drawn upon when the need arises. One benefit of this strategy is that the Turner and Soldier-Pope pumping systems operate efficiently when the springs are flowing at or above their historical rate of discharge. This conservative strategy, however, does not take full advantage of the aquifer in view of recent hydrogeologic information and analysis provided in Technical Memorandum No. 2.

Any adjustment to the current groundwater management has been unnecessary because of the decline in demand that has persisted from 2003 to 2014. Groundwater production has declined because of the reduced need to supplement surface water production. However, it should be recognized that this does not need to be the groundwater operation paradigm.

As will be discussed in Technical Memoranda No. 2 and No. 4, the City has the option to use the Casper Aquifer more aggressively, if need be.

For the past 143 years, the City's groundwater supply has focused exclusively on the Casper Aquifer. This focus will continue because of the excellent water production and water quality from the Casper, the enormous storage capacity, and the substantial investment in groundwater extraction infrastructure.

VII. Production Well Construction, Equipment, and Maintenance

Table TM 1-2 lists production well construction and pump system equipment information. Aside from changes in aquifer hydraulics, declines in production from a well can be attributed to physical, chemical, and biological processes that compromise pumping equipment such as the motor, pump bowls, line shaft, drop pipe, pump intake, electrical wiring, and the biofouling, mineral precipitation, or collapse of the wellbore. Despite the advanced age of most of the production wells, there have not been systematic problems with well infrastructure.

To identify potential problems, the City should annually verify that well production is within established limits of pump system capability. An annual check-up for each well should be performed that consists of: 1) comparison of static water levels with a similar time-of-year in previous years to assess changes in the aquifer; 2) comparison of specific capacity values with previous years to assess changes in the well; and 3) comparison of observed pump performance (measured gpm at measured total dynamic head) with manufacturer's pump curve to assess changes in the pumping equipment.

Because the sandstone and limestone of the Casper Aquifer have excellent integrity and rarely collapse, the municipal production wells are "open hole" completions. Steel casing is set and cemented into the top of the formation and the borehole beneath the casing is drilled to total depth. The wells are left in this open hole condition beneath the casing. Complicated and problematic well completions involving screen and filter pack are typically not necessary. An exception is Soldier No. 1 which has 20 feet of screen at the top of the formation, but the majority of the well is open hole.

In 2004, the City pulled the line-shaft turbine pump from Turner No. 2 to inspect the casing and open hole. Due to drawdown during consecutive pumping cycles, the pump run-times were less than previous years. The inspection was to identify obvious downhole obstructions or related problems that could affect drawdown. While the pump was out of the well to be serviced, a downhole camera survey was performed to observe the condition of the casing and open hole (wellbore). The casing appeared to be in good condition and there were no observable biological, chemical, or physical problems with the wellbore (Wyoming Groundwater, 2004). A thin layer of calcium carbonate precipitate coats the interior surface of the casing which probably helps to reduce casing corrosion. To increase available drawdown, the pump was reinstalled with additional column pipe such that the top of pump bowl was lowered to approximately 92 feet.

In 2007, the City pulled the line-shaft turbine pump from Pope No. 2 to replace the pump, repair/maintain the line shaft, and install a functional bubbler system to monitor water level. While the pump was out of the well, a downhole camera survey was performed to observe the condition of casing and open hole. There were no apparent issues with casing or wellbore integrity (John Wetstein, pers. comm., 3/10/15). Although the Pope Nos. 1, 2, and 3 wells are 78 years old, the condition of Pope No. 2 suggests that the steel casings and wellbores in these three old wells and in the more recent Pope No. 4 well are probably in reasonably good condition. When the pumps at other Pope wells are removed for service or repair, a downhole camera survey should be performed to assess the condition of the casing and wellbore.

In 2011, the City pulled the line-shaft turbine pump from Turner No. 1 for inspection and repair. While the pump was out of the well, a downhole camera survey was performed to observe the condition of the casing and open hole. The casing appeared to be in good condition and there where no observable problems with the wellbore (Wyoming Groundwater, 2011a). A thin layer of calcium carbonate precipitate coats the interior surface of the casing, which probably helps to reduce corrosion. The pump was reinstalled with the top of the pump bowl at approximately 82 feet.

There has not been any well/pump maintenance issues associated with Spur No. 1 and Spur No. 2. In 2007, a defective bubble tube was replaced at Soldier No. 1. Given that the Spur and Soldier well infrastructure was installed in 1997, the casings are probably in excellent condition. When the Spur and Soldier well pumps are removed for service or repair a downhole camera survey should be performed to assess the condition of the casing and wellbore.

An unusual aspect of the construction of Turner No. 1 is illustrated in Figure TM 1-8. The casing was set 5 feet above the top of the Casper Formation and the annular space behind the casing from 50 to 100 feet was filled with gravel instead of cement grout. The gravel was probably installed due to a concern that the cement grout would flow into and plug permeable fractures in the upper-most part of the Casper Formation. The gravel-filled interval adjacent to the lower-most 50 feet of the Satanka Shale is problematic because it provides hydraulic communication and possible leakage between the Casper Aquifer and the overlying Satanka Shale. This condition also exists, although to a lesser degree, at Turner No. 2.

<u>Water Levels During Pumping at Municipal Production Wells</u>

The operation of a groundwater production well is constrained by well design and aquifer hydraulics. These two elements define the amount of drawdown that is available during pumping. For example, if the pump intake is set at 100 feet and the non-pumping (static) depth to water is 20 feet, the water level in the well can decline 80 feet during pumping before the pump begins to “suck air”. General practice is for low-level controls in a well to shut the pump off when the water level is within 10 feet of the pump intake.

The amount of drawdown that occurs during pumping depends on the pumping rate and the permeability of the aquifer. This relationship is expressed by the specific capacity of the well (i.e. gallons per minute per foot of drawdown). Low specific capacity is offset by maximizing the available drawdown with deep pump settings in long production casing. In all but one of the City municipal wells, the bottom of the production casing is at or near the top of the Casper Formation and the pump is installed at the bottom of the casing just above the open hole. Setting the pump in the open hole portion of a well is possible, but is not good practice because of the potential for wellbore collapse onto the pump.

With these things considered, Table TM 1-2 lists the available drawdown and pumping depth to water at each municipal production well. In combination with specific capacity values for each well as listed in Table TM 1-1, the following observations can be made regarding the duration of pumping from the municipal wells.

- Spur No. 1 and Spur No. 2 experience so little drawdown during pumping at current design rates that the wells can be pumped solo or simultaneously for as long as needed.
- Turner No. 1 and Turner No. 2 can be operated solo at current design rates for as long as needed.
- When Turner No. 1 and Turner No. 2 are operated simultaneously the available drawdown in both wells becomes a limiting factor and run times are reduced.
- Because the high yield Pope No. 3 and No. 4 wells are operated solo, the drawdown caused by pumping at current design rates is not a limiting factor in the operation of these wells for as long as needed.
- Soldier No. 1 experiences so little drawdown during pumping at current design rates that the well can be pumped for as long as needed.

The only identified limitation of wellfield pumping and operation is at the Turner Wellfield. During repeated cycles of simultaneous operation of the Turner wells, the water level in Turner No. 1 will trigger the automatic pump shut-off and thereby limit the run-time of simultaneous operation of the two wells. Based on pumping rates and specific capacity values, the Turner No. 2 would seem to be the most likely Turner well to experience the magnitude of drawdown needed to trigger the automatic shut-off of the well; however, of the two Turner wells, it is Turner No. 1 that typically shuts-off first. This discrepancy may warrant further evaluation.

The above discussion regarding well operation and capability does not take into account the consequences of temporary supply reduction that results from the slow recovery of the aquifer and/or the reduced artesian or pumping production that occurs during and after a long period of maximum wellfield production.

VIII. Groundwater Supply Summary

Since 1868, the Casper Aquifer has provided the City of Laramie with a reliable water supply. The development and conjunctive use of surface water and groundwater has created an exceptionally robust and flexible water supply system that will serve the City for many years to come.

Characteristics of the Casper Aquifer that demonstrate its excellence as a municipal water supply are listed below.

- High yield production wells with large specific capacities, shallow total depths, and low dynamic head (i.e. shallow depth to water during pumping)
- Stable open hole well completions with low maintenance, high efficiency, and low potential for biological fouling
- Low cost well construction and operation compared to municipal well systems with much deeper wells and greater depth to water
- Gravity flow from the Soldier-Pope Wellfield to the low-level reservoir
- Proximity of the aquifer and wellfields to City infrastructure and points-of-use (i.e. within 6 miles)
- Exceptional water quality (see Technical Memorandum No. 3).

We hope this technical memorandum and those that follow impress upon the reader how remarkable the Casper Aquifer is and how fortunate the City is to be able to take advantage of this resource. After 30 years of working with municipal water systems throughout Wyoming, in our opinion, the Casper Aquifer in the vicinity of Laramie is the best municipal water source in Wyoming.

IX. Wellfield and Well Monitoring

The City water system operator/supervisor, Mike Lytle, has developed a sophisticated and comprehensive SCADA system that monitors and controls the surface water and groundwater infrastructure. With respect to the wellfields, the SCADA system measures, controls, and archives the following groundwater system parameters at 5 minute intervals:

- Water levels in production wells using bubbler tubes
- Water production from the Soldier, Pope, Turner, and Spur wellfields and at selected individual wells: Soldier No. 1, Spur No. 1, and Spur No. 2
- On/off well control with low-level alarms and shut-offs at each well
- Power status at each wellfield
- Groundwater treatment control and status
- Turbidity at Soldier No. 1
- Valve control in Soldier and Spur pipelines
- Variable production using variable frequency drive motor control at Soldier No. 1

Water system data are archived as a permanent record which provides a wealth of data for system evaluation and analysis.

IX. Non-Municipal Groundwater Users

In the vicinity of Laramie, other users of groundwater from the Casper Aquifer include private domestic wells at county residences, the Mountain Cement plant south of Laramie, and a few institutional facilities (Cathedral Home, WyoTech Institute, and Western Research Institute) at the north end of 3rd Street[2].

County Residences

An estimated 550 county residences obtain water from the Casper Aquifer in the area between the Spur and Simpson Springs (WWC Engineering, 2006). Based on an estimate of 0.4 ac-ft/yr for average rural domestic net groundwater consumption (States West Water Resources, 1993), the net extraction of groundwater for this population is approximately 0.2 mgd. Much of the water pumped by residential systems is returned to the aquifer via the on-site septic system. Thus, only the "net" withdrawal is accounted here.

Mountain Cement

Mountain Cement has five wells completed in the Casper Aquifer that provide water for cement processing and facility operations. The State Engineer's Office does not have annual production records from the Mountain Cement production wells on file and Mountain Cement was unable to provide well production records.

The combined permitted instantaneous water right of these five wells is 620 gpm which equates to 0.89 mgd. It is unlikely that the wells are operated continuously, so average annual production is likely to be significantly less than the permitted instantaneous use. A reasonable first approximation is that total annual production from the Mountain Cement wells is 50% of permitted production or approximately 0.45 mgd. Mountain Cement may be the second largest Laramie-area user of groundwater from the Casper Aquifer (i.e. the City of Laramie is the largest user). Future groundwater use planning efforts should include obtaining well production records from Mountain Cement.

Cathedral Home, WyoTech Institute, and Western Research Institute

The combined permitted production from two wells at Cathedral Home, two wells at WyoTech Institute, and four wells at Western Research Institute (Plate I) is 489 gpm which equates to 0.70 mgd. It is unlikely that these wells are operated continuously, so average annual production is likely to be significantly less than the permitted instantaneous use. A reasonable first approximation is that total annual production from

[2] The instantaneous permitted water right almost certainly overestimates actual groundwater production. Well production data are not on file at the State Engineer's Office. An accurate groundwater use inventory from industrial and institutional wells will require obtaining well production records from these institutions.

these three facilities is 50% of permitted production or approximately 0.35 mgd. Future groundwater use planning efforts should include obtaining well production records from these three facilities.

University of Wyoming

There are three wells completed in the Casper Aquifer on the UW campus (Plate I). One well (University Well #3; U.W. 495) was drilled in 1893 to a total depth of 1,040 feet and is located in the basement of the Biological Sciences building. UW #3 has a water right of 15 gpm and was used in the past for fish rearing research projects. The well is not being used currently. The "Petro Well" is located between the Wyoming Geological Survey and the Engineering buildings. The Petro well is not being used for water supply purposes and details regarding the well are provided in Weston Engineering (2013b). A third well identified as "University well no. 2" by Morgan (1947) has a total depth of 1,241 feet and is mentioned to be located "near the Men's Residence Hall on the campus." Other than the lithology log provided by Morgan, there is no other information available regarding this well.

There are two wells completed in the Forelle Limestone (i.e. a redbed formation) that are used for on-campus lawn watering and irrigation. The "Fine Arts" well is located north of the Fine Arts Building and the "West Campus Well" is located near the corner of 15th and Willet streets (Plate I). Details regarding these Forelle wells are provided in Weston Engineering (2013b). UW has been using water from the Forelle to irrigate campus green areas since 1939.

List of Tables

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1. Spur Wellfield Use Agreement

TECHNICAL MEMORANDUM NO. 1

TABLES

Table TM 1-1: Production Characteristics of Laramie Municipal Wells. 2015 Laramie Master Plan, Level I

Well Name	Approx. Static Depth to Water, ft.	Test Duration, days	Test Pumping Rate, gpm	Drawdown End of Test, ft.	Well Specific Capacity gpm/ft.	Multi-Well "Specific Capacity[1]" gpm/ft.	Current Max. Well Pumping Rate, gpm
Spur No. 1	32	6.0	2,000	3.4	580	200	1,560
Spur No. 2	12	5.0	2,000	4.5	440	200	1,560
Turner No. 1	0	6.9	2,030	30.5	66	43	2,200
Turner No. 2	+6	1.4	1,730	47	36	21	1,700
Pope No. 1	11	1.0	475	12	40		475
Pope No. 2							650
Pope No. 3	15	1.0	994	16	62		994
Pope No. 4	31	2.0	1,500	12	125		1,935
Soldier No. 1	+2	5.8	1,800	9.4	191		2,300

Note 1 : Multi-Well "specific capacity" refers to the gpm/ft when both Spur No. 1/No. 2 and Turner No. 1/No.2 are operating

Table TM 1-2: Municipal Production Well Completion Data. 2015 Laramie Master Plan, Level I

Wellfield and Well Name	Year Drilled	Total Depth, ft.	Cased Interval, ft.	Casing OD, in.	Open Hole Interval, ft.	Open Hole Dia., in.	Approx. Bubbler Set Depth, ft.	Top of Pump Intake, ft.	Approx. Static DTW, ft.	Approx. Available Drawdown[1], ft.	Approx. Pumping Drawdown[2], ft.	Well Pumping Rates[3], gpm	Pump Type/Mfg: Year[4]	Motor Rating, hp
Spur Wellfield														
Spur No. 1	1997	305	0 - 91	16	91 - 305	14.75	78	83	32	41	3	1,560	LST/Floway 12JKH: 2000	100
Spur No. 2	1997	323	0 - 255	16	255 - 323	14.75	68	73	12	51	6	1,560	LST/Floway 12JKH: 2000	100
Turner Wellfield														
Turner No. 1	1982	240	0 - 98.4	16	98.4 - 240	12.25	80	86	0	76	33 / 51	2,200	LST/Layne: 2011	40
Turner No. 2	1982	350	0 - 100	16	100 - 350	12.25	80	96	+6	92	47 / 81	1,700	LST/Vertiline: 2004	40
Soldier-Pope Wellfield														
Pope No. 1	1937	156	0 - 64	8	64 - 156	7.25	54	59	11	38	12	475	LST/Aurora 1130: 1937	7.5
Pope No. 2	1938	162	0 - 64	8	64 - 154	7.25	58	61	22	29		650	LST/Gould 8DHCWL: 2007	10
Pope No. 3	1939	158	0 - 66	15	66 - 158	14	62	66	15	41	16	994	LST/Aurora 1130: 1982or39	40
Pope No. 4	1982	350	0 - 100	16	100 - 350	12.25	76	80	31	39	15	1,935	LST/Aurora 1130: 1982	75
Soldier No. 1	1997	289	0 - 79.5 Screen 44.1 - 64.4	16	79.5 - 289	13.75	40	44	+2	36	12	1,300 flowing 2,300 pumping	LST/Floway VFD: 1998	75

Notes: All depths are relative to ground surface
1 : Available drawdown is static depth to water minus pump intake depth minus 10 feet
2 : Pumping drawdown is well pumping rate divided by specific capacity of the well (see Table TM 1-1); single value is solo operation; second value is both Turner wells on simultaneously
3 : Pumping rates are current maximum values. Well pumping rates will vary seasonally depending on wellfield operation history, duration of pumping, and hydraulic conditions of the aquifer
4 : Year that pump was installed or last serviced
LST = Line Shaft Turbine
VFD = Variable Frequency Drive motor control

Table TM 1-3: Spur Wellfield Agreement Drawdown/Production Specifications and Compliance Baselines

Spur Wellfield Production Limits

Drawdown at Monitoring Wells per Agreement, ft.	Max. Annual Wellfield Withdrawal Volume, acre-ft (*mg*)	Max. Daily Wellfield Production Rate, mgd
< 20	1200 (*391*)	4.0
20 - 25	900 (*293*)	3.0
25 - 30	600 (*195*)	2.0
30 - 35	300 (*98*)	1.0
> 35	0 (0)	0

Monitoring Well Baselines

Monitoring Well	Top of Well Casing Elevation, ft.	Water Surface Elevation Measured Just Prior to the August 22, 1997, Pump Test, ft.	Depth to Water, ft.
MW-7	7365.7	7259.7	106.0
MW-8	7371.7	7262.3	109.4
MW-10	7368.3	7262.3	106.0
MW-11	7380.4	7260.0	120.4
MW-12	7425.8	7283.5	142.3

Table TM 1-4: Demonstrated Reliable Wellfield Production over Specific Durations of Pumping.
2015 Laramie Master Plan, Level I

Wellfield	Instantaneous[1] mgd	Peak Day[2] mgd	1-Week[2] mgd	1-Month mgd	3-Month mgd
Soldier-Pope	6.0	4.5 (2002)	4.9 (2002)	4.9 (2002)	4.4 (2002)
Turner	5.4 (2015)	2.5 (2002)	2.5 (2002)	2.5 (2002)	2.4 (2002)
Spur	4.5 (2015)	4.0[3] /4.2 (2002)	4.0[3] /4.2 (2002)	4.0[3] /4.2 (2002)	3.3 (2002)

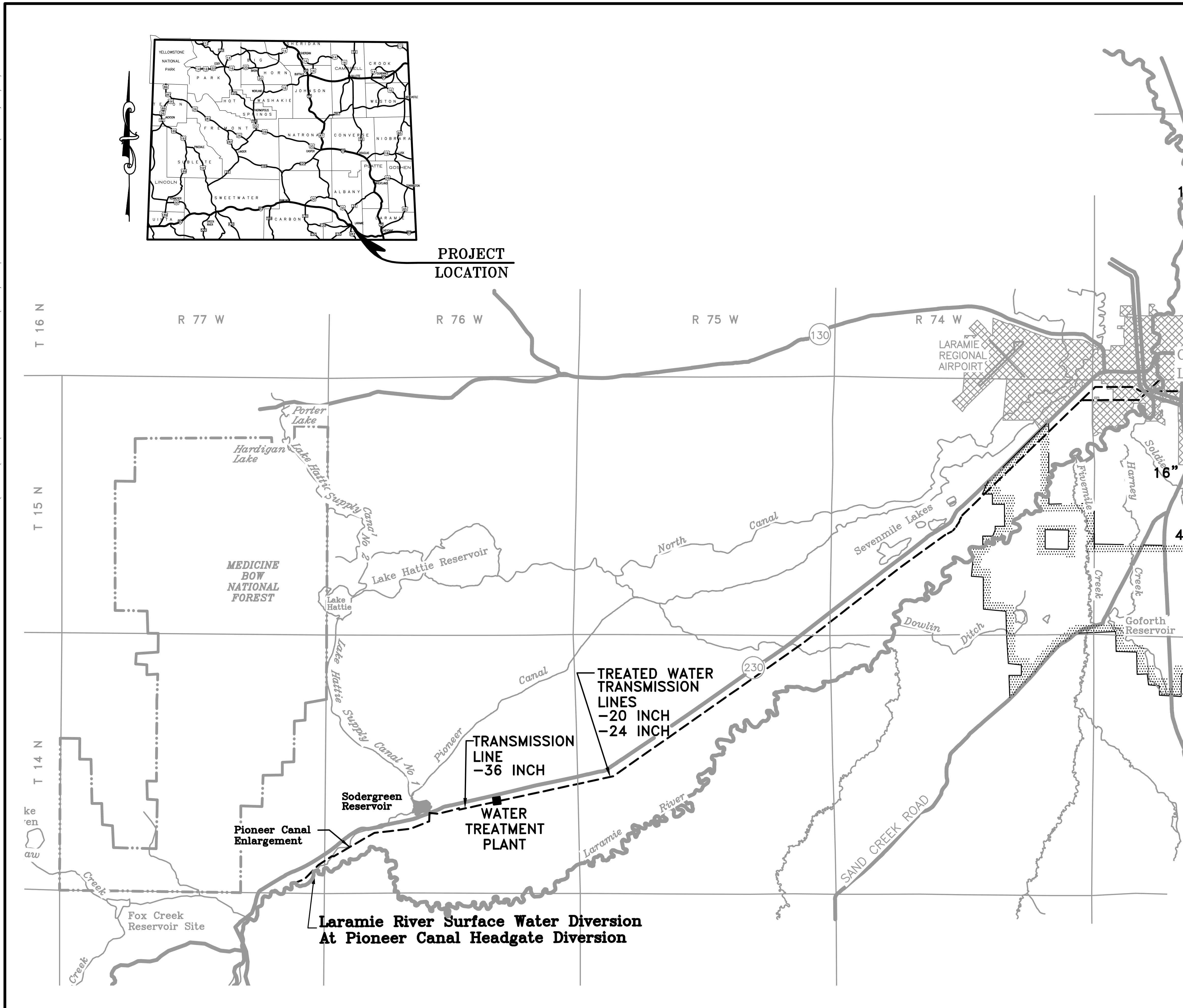
Note: 1: Instantaneous values are the demonstrated maximum production rate from the wells (combined) used to achieve maximum wellfield production. These values may not be sustainable during high demand periods or during sustained pumping of multiple wells.

2: Peak Day and 1-Week values are derived from 1-Month production during the summer of 2002 when wellfield production was at a maximum. These values are conservative but considered to be highly reliable under operational and hydrologic conditions that can be reasonably anticipated.

3: 4.0 mgd is the maximum allowable daily production rate per the Spur Use Agreement. Actual daily production from the wellfield during the summer of 2002 was slightly higher.

TECHNICAL MEMORANDUM NO. 1

FIGURES



DESIGNED BY: MTS	FIGURE TM 1-1 LOCATION MAP OF LARAMIE WATER SOURCES
DRAWN BY: SDH	
CHECKED BY: MTS	2015 LARAMIE WATER MASTER PLAN, LEVEL I WYOMING WATER DEVELOPMENT COMMISSION
DATE: 06/15	WWC ENGINEERING

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DESIGNED BY: JRA	FIGURE TM 1-2
DRAWN BY: JRA	SOLDIER WELLFIELD LAYOUT
CHECKED BY: MTS	2015 LARAMIE WATER MASTER PLAN, LEVEL I WOMING WATER DEVELOPMENT COMMISSION LARAMIE, WYOMING
DATE: 08/15	WWC ENGINEERING

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DESIGNED BY: JRA	FIGURE TM 1-3
DRAWN BY: JRA	POPE WELLFIELD LAYOUT
CHECKED BY: MTS	2015 LARAMIE WATER MASTER PLAN, LEVEL I WOMING WATER DEVELOPMENT COMMISSION LARAMIE, WYOMING
DATE: 08/15	WWC ENGINEERING

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SCALE

DESIGNED BY: JRA	FIGURE TM 1-4
DRAWN BY: JRA	TURNER WELLFIELD LAYOUT
CHECKED BY: MTS	2015 LARAMIE WATER MASTER PLAN, LEVEL I WOMING WATER DEVELOPMENT COMMISSION LARAMIE, WYOMING
DATE: 08/15	WWC ENGINEERING

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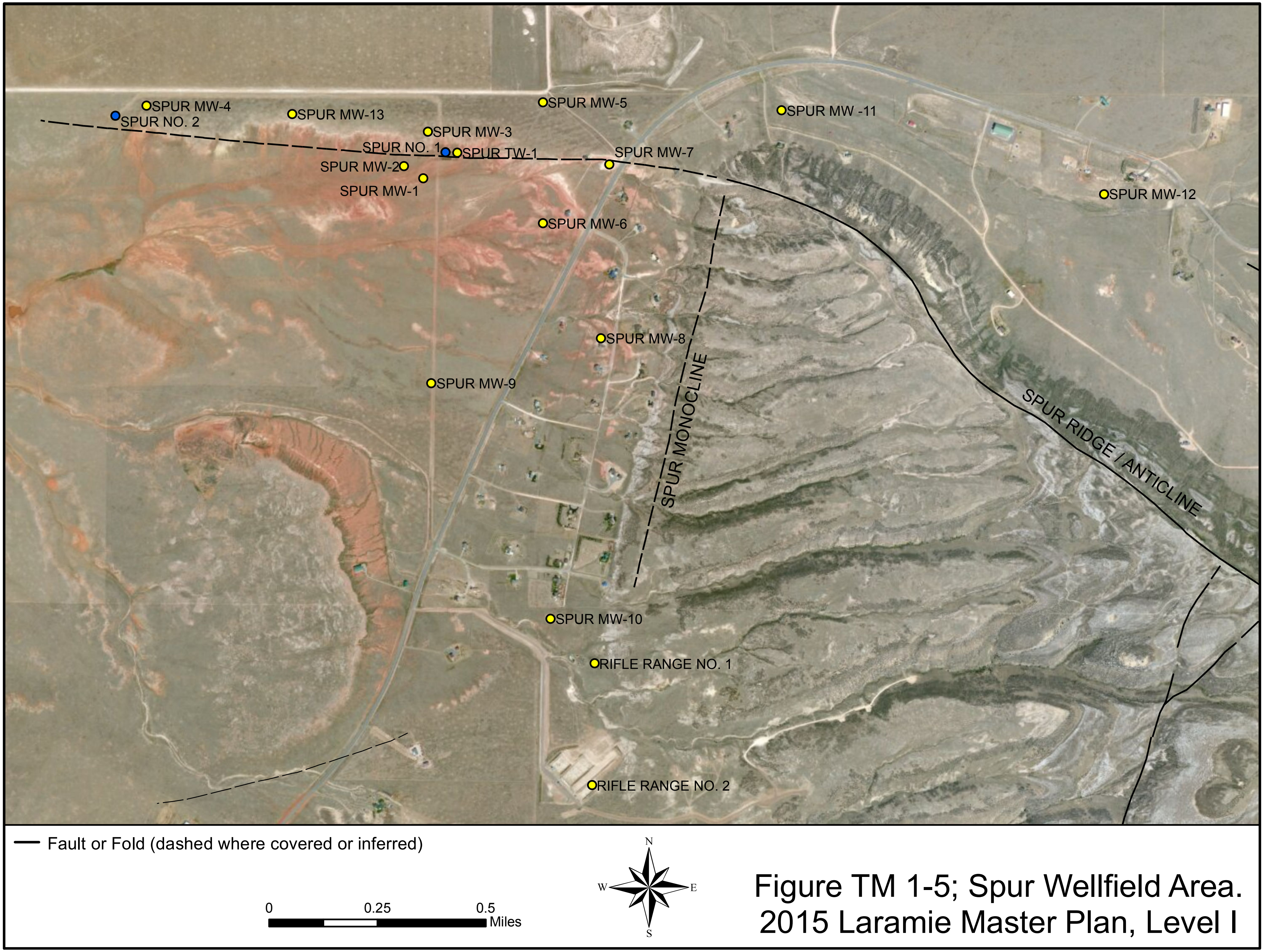


Figure TM 1-5; Spur Wellfield Area.
2015 Laramie Master Plan, Level I

Figure TM 1-6: Groundwater and Surface Water Production: 1999 to 2014
2015 Laramie Master Plan, Level I

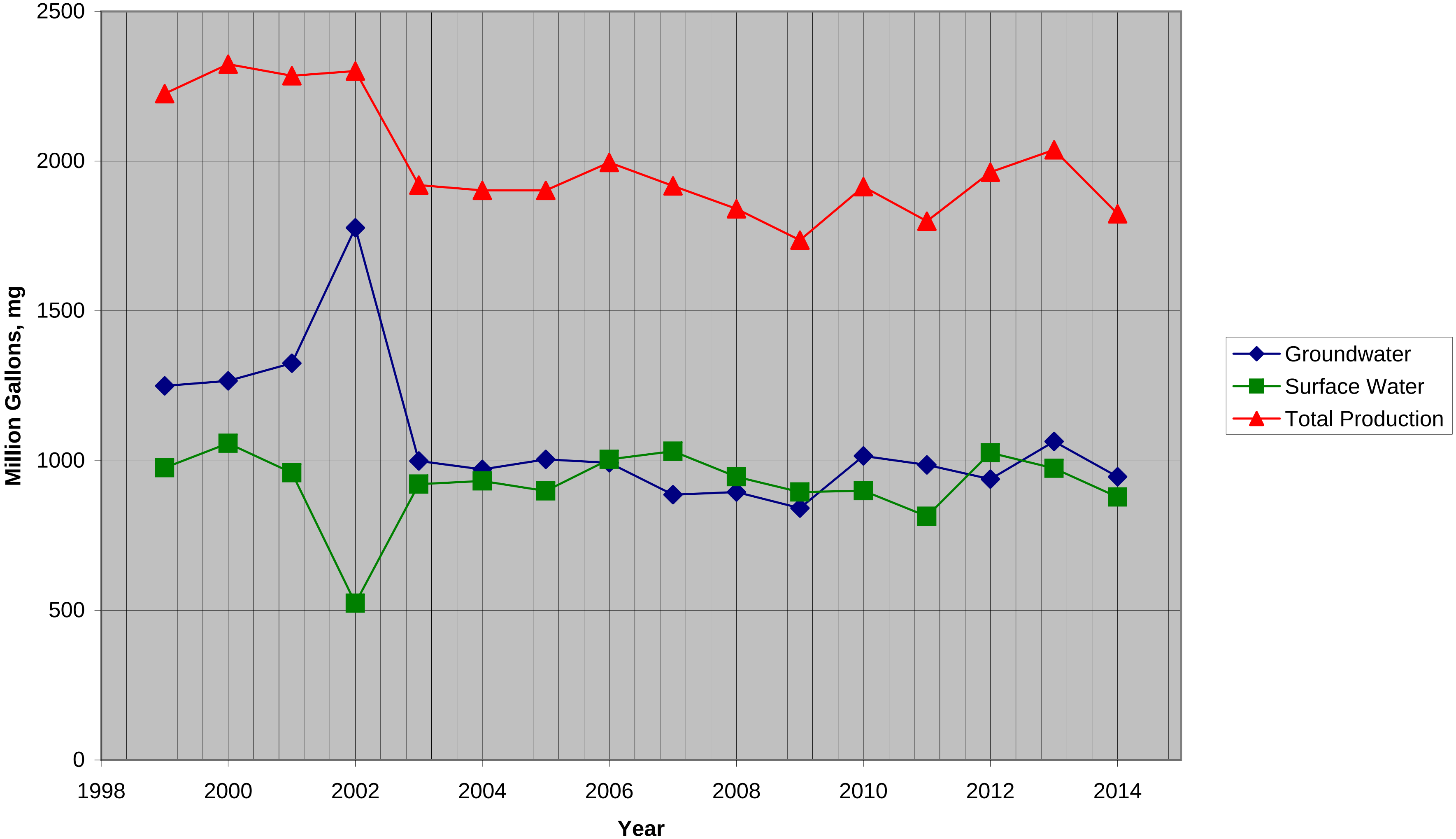
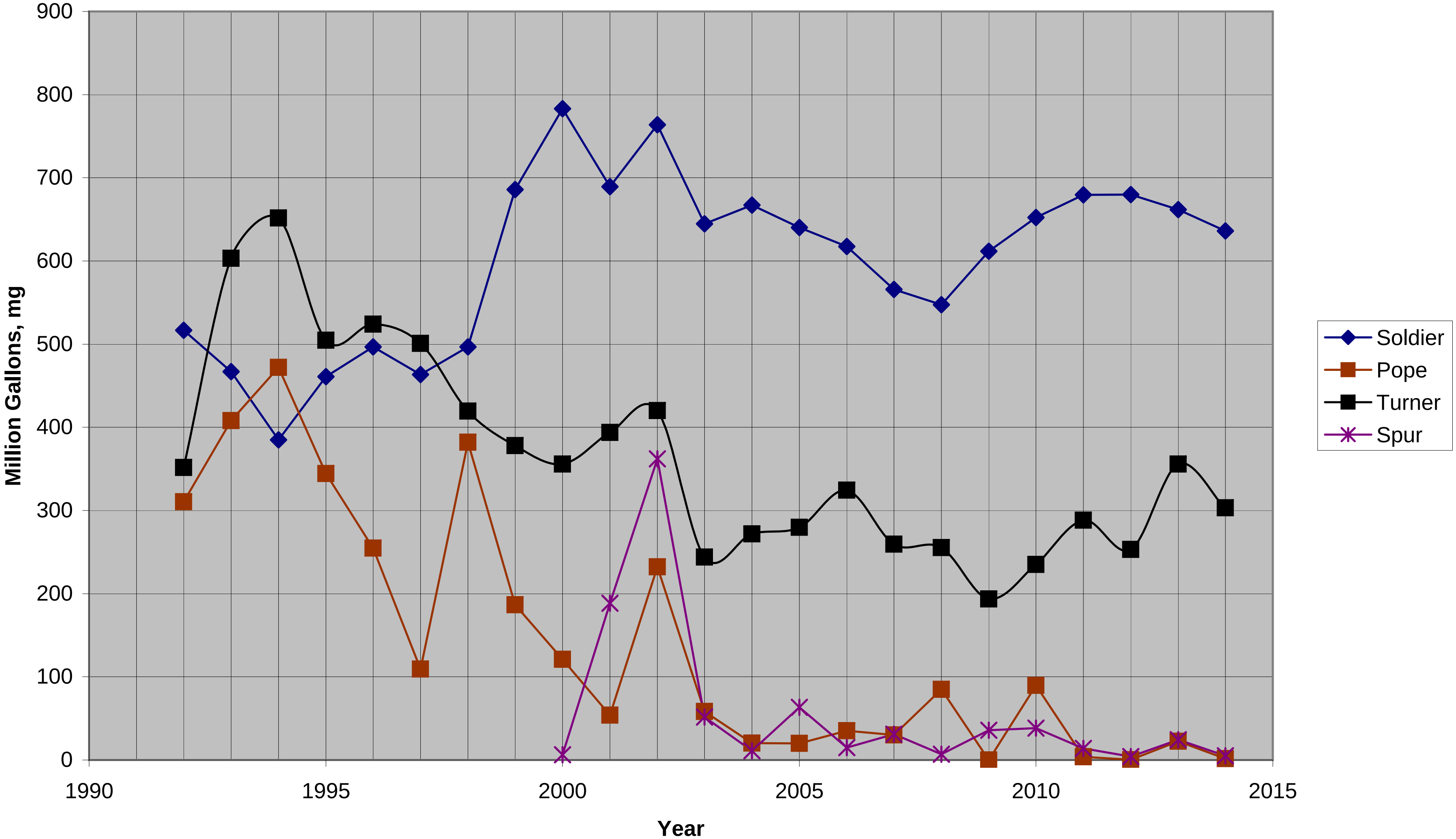
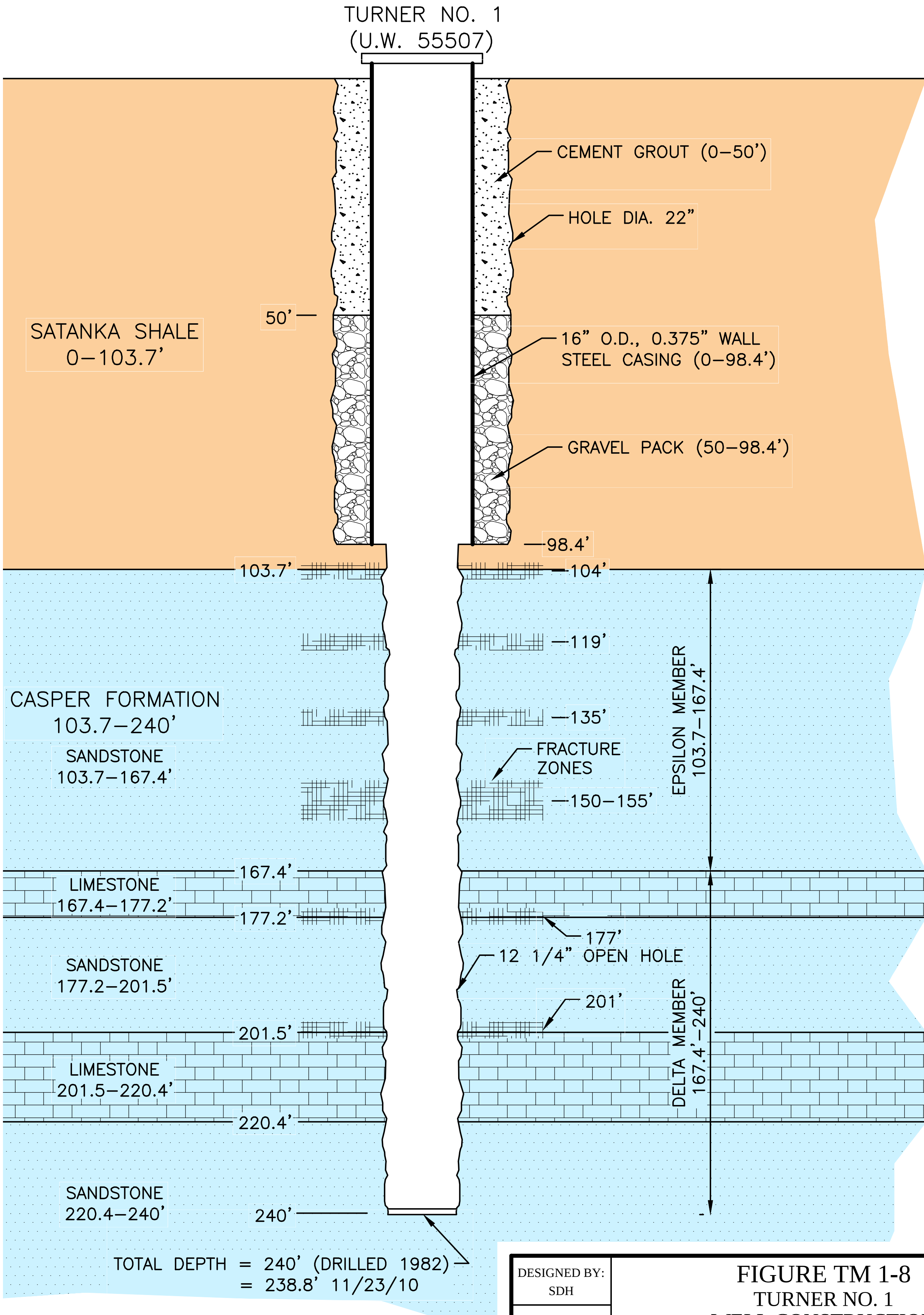


Figure TM 1-7: Laramie Wellfield Production - 1992 to 2014
2015 Laramie Master Plan, Level I





MODIFIED FROM BANNER ASSOCIATES (1982)
AND DOWNHOLE CAMERA SURVEY (11/23/10)

DESIGNED BY: SDH	**FIGURE TM 1-8** TURNER NO. 1 WELL CONSTRUCTION
DRAWN BY: SDH	
CHECKED BY: MTS	2015 LARAMIE WATER MASTER PLAN, LEVEL I WOMING WATER DEVELOPMENT COMMISSION LARAMIE, WYOMING
DATE: 09/15	WWC ENGINEERING

TECHNICAL MEMORANDUM NO. 1

ATTACHMENT 1

SPUR WELLFIELD USE AGREEMENT

Chris Mooney

BEFORE THE STATE ENGINEER

STATE OF WYOMING

IN RE PETITION FOR CHANGE IN LOCATION OF SPUR NO. 2 WELL, PERMIT NO. U.W. 106548; UNADJUDICATED PRIORITY DECEMBER 1, 1994; LARAMIE UNDERGROUND WATER DISTRICT	)
GEORGE HOOD, JUDY HOOD, STEPHEN JACKSON, ANNE M. BOWEN, K. KIM KELLOGG, CINDY KELLOGG, HOWARD (CASH) CARROLL, DIANA KOCORNIK WAYNE SUTHERLAND, PAUL FLESHER, WILLIAM BAKER, DEBORA PAULSON,	)
Contestants,	)
vs.	)
CITY OF LARAMIE,	)
Contestee.	)

MAR 27 1998
STATE ENG
Cheyenne,

State Engineer Docket No. 97-4

STIPULATION AND AGREEMENT--CITY OF LARAMIE AND VARIOUS CONTESTANTS

The City of Laramie filed a request to relocate its Spur No. 2 Well, Permit No. UW 106548. Some persons filed timely protests to the relocation. The Spur No. 1 Well and Spur No. 2 Well (Permit Nos. U.W. 106547 and U.W. 106548 respectively) now comprise the City's Spur Well Field. Through negotiation, the City and the parties have arrived at a method of operation of the Spur Well Field, which is intended to permit the City to use the water resource, while affording protection to current and future domestic and stock wells which might be affected by the City's operation of the Spur Well Field. In settlement of the controversy, the parties stipulate and agree as follows:

1. The parties intend that this stipulation be made a part of the record in this contested case.

2. The parties intend that the State Engineer shall incorporate the terms of this stipulation as operating conditions upon the Spur No. 1 Well and Spur No. 2 Well as relocated. Any expansion (new wells or permit enlargements) of the well field will also become subject to the collective acre feet per year limit.

3. The City will monitor its monitoring wells MW-7, MW-8, MW-10, MW-11, and MW-12, shown upon the map attached hereto as Exhibit A. Interested domestic and stock well owners will be allowed to accompany City personnel while they are collecting aquifer data. These five monitoring wells were strategically located to assess aquifer drawdown characteristics in neighboring subdivisions to the east of the City's Spur Well field.

4. The City will monitor the new Warren well C 121 (Warren No. 1 Well, SE¼SE¼ Section 33, T. 17 N., R. 73 W.) which is located west of the Spur Wells field.

5. It is the City's intent to provide monitoring equipment in MW-7, MW-8, MW-10, MW-11, and MW-12 that will measure and record drawdown depths on a daily basis. A copy of all drawdown measurements will be provided within a reasonable time after collection to the State Engineer's Office and will be made available for review in the office of the City of Laramie Director of Public Works.

6. Private domestic wells in the vicinity of each of the five monitoring wells have been analyzed with regards to depth of well and depth of pump setting below the static water level. The private wells were grouped around the respective monitoring wells that most closely reflect their conditions. Then the private well with the smallest distance between its pump setting and static water elevation was selected as the control situation. The full tabulation of well data is attached and is summarized below:

<u>MW-7</u> Control Well (Bury)

Depth of well	200 feet
Depth of pump	188 feet
Depth to static water level	<u>120</u> feet
Water column height above pump	68 feet

<u>MW-8</u> Control Well (Meacham) (Attebery well judged to be inadequate)

Depth of well	175 feet
Depth to pump	165 feet
Depth to static water level	<u>105</u> feet
Water column height above pump	60 feet

<u>MW-10</u> Control Well (Fluty)

Depth of well	175 feet

Depth to pump	170 feet
Depth to static water level	105 feet
Water column height above pump	65 feet

MW-11 Control Well (Schlosser)

Depth of well	280 feet
Depth to pump	265 feet
Depth to static water level	160 feet
Water column height above pump	105 feet

MW-12 Control Well (Borgialli)

Depth of well	380 feet
Depth to pump	320 feet
Depth to static water level	218 feet
Water column height above pump	102 feet

7. Drawdown is defined as the distance between measured water surface in a monitoring well and the initial water level measured in that well prior to initiation of the Spur Well No. 1 pump test on August 22, 1997. The following values represent initial water level elevations that will be used to establish drawdown:

Monitoring Well	Top of Well Casing Elevation	Water Surface Elevation Measured Just Prior to the August 22, 1997 Pump Test
MW-7	7365.7	7259.7
MW-8	7371.7	7262.3
MW-10	7368.3	7262.3
MW-11	7380.4	7260.0
MW-12	7425.8	7283.5

8. The City will place the following constraints upon its collective operation of its Spur Well field:

Drawdown in MW-7 MW-8, MW-10, MW-11, or MW-12	Maximum Annual Withdrawal Rate (acre-feet per year)	Maximum Daily Withdrawal Rate (MGD)
0-20 feet	1200	4.0
20-25 feet	900	3.0
25-30 feet	600	2.0
30-35 feet	300	1.0
Greater than 35 feet	0	0

9. Additionally, the City agrees to further restrict annual withdrawal rates in the first two years of operation as follows:

A. First year of operation - annual withdrawal shall not exceed 400 acre-feet.
B. Second year of operation - annual withdrawal shall not exceed 800 acre-feet.

10. The drawdown measurements on May 15th of each year will be used to determine maximum annual withdrawal rates for the next twelve months. The drawdown measurements taken on the 1st and 15th of each month will be used to determine the maximum daily withdrawals for the upcoming 15 to 16 day period in June through September. The drawdown measurements taken on the 1st of each month will be used to determine daily withdrawals for the upcoming 28 to 31 day period in October through May. The greatest drawdown in the five sampled monitoring wells will be the drawdown used to set the control program.

11. Water levels in the Warren will be monitored but will not be used as a control mechanism for this program. This well and others which penetrate the Casper formation in the Aliquot Subdivision have static water levels 600 plus feet above the Casper formation which allows much more operational flexibility than private wells located near MW-7, 8, 10, 11, and 12.

12. Twenty years after beginning production, the City may elect to petition the State Engineer's Office to modify the monitoring program and other appropriate conditions of the permit, based upon the twenty years of data related thereto. The State Engineer will provide an adequate public notice and comment period as required by Wyoming statutes and regulations in place at that time. The City will provide notice to the signatories to this stipulation or their successors in interest, who shall have the full right to appear and be heard regarding any request to modify these permit conditions.

13. A. The City of Laramie will perform all necessary water quality analyses to assure full compliance with federal Safe Drinking Water Act requirements for water produced from its Spur Wells. Additionally, the City will monitor total dissolved solids, major cations, and major anions in the production water.

B. The City will evaluate these water quality results over time so as to detect possible aquifer contamination. One example of potential contamination is the leachate from private on-site wastewater disposal systems. If aquifer contamination is detected, the City will seek voluntary cooperation from the affected landowners to identify and correct the problem. It is the City's intent to negotiate individual agreements with adjacent property owners that will establish the framework to jointly resolve aquifer contamination problems.

C. If TDS equals or exceeds 700 ppm in Spur Well water, the City will take water samples from each of the monitoring wells and analyze the samples for TDS. If TDS in any of the monitoring wells equals or exceeds 700 ppm, the City will notify domestic well owners within the scope of the monitoring well network, and will take reasonable steps to remedy the situation. "Reasonable steps" may include, but are not limited to, reduction in Spur Well Field withdrawals irrespective of drawdown, providing alternate domestic water to well owners whose individual wells test >700 ppm TDS, or cessation of withdrawals from the Spur Well Field until sampling shows reductions in TDS to <700 ppm.

14. A. If the City is unable to meet municipal water demand due to an emergency situation in the first two years of operation, the City may exceed the agreed annual withdrawal limitation during those years. Upon declaration of emergency, the City will notify the State Engineer's Office and adjacent landowners of said emergency and its intent to exceed the year 1 and 2 withdrawal limit, subject to the constraints described in Table 2.

B. If the City operates above the volume limitations during the first two years, the City will extend the period of restricted withdrawals under paragraphs 9 A and B for an equal amount of time.

C. An emergency may include, but is not limited to: mechanical or electrical failure which adversely affects the City's ability to deliver water from surface or other underground water sources; temporary increased demand due to conditions beyond the City's control (not caused by unforeseen increases in customer base); casualty to the water treatment plant which reduces or eliminates its ability to deliver treated water; and failure of part of the delivery system which prevents or substantially reduces the City's ability to deliver water from a surface or another underground source.

15. The City will abandon the existing originally permitted location of the Spur No. 2 Well.

16. All contestants who have signed below shall withdraw their protests to the relocation of the Spur No. 2 Well.

17. This stipulation will be null and void if the conditions contained herein are not incorporated as permanent conditions in permit numbers 106547 and 106548 for the Spur No. 1 and Spur No. 2 wells.

18. This stipulation is entered into by the City based upon the City's conclusion that the execution of this stipulation will definitely and discernibly benefit the City of Laramie and its residents by assuring the development and maintenance of the groundwater supply associated with the operation of the Spur well field. The extended temporal term of this stipulation is necessary to protect the public interest by defining the operation of the Spur well field in a manner which assures certainty of water supply for the residents of the City while minimizing the possibility of interruption in the operation of the well field.

19. Each party executing this agreement warrants and represents that they have all necessary power and authority to execute the agreement and that, where necessary, they are acting pursuant to duly authorized and adopted resolutions of the governing bodies.

20. This stipulation may be executed in any number of counterparts, each of which shall operate as an original instrument, and all of which together shall constitute one and the same instrument.

In witness whereof, the undersigned City of Laramie and protestants have signed this stipulation at Laramie, Wyoming, on the dates shown below.

The City of Laramie

By: ______________________ Date: 3/26/98
Authorized Signature

Signatures of Contestants:

Wayne M. Sutherland Date: March 23, 1998	Date: 3/24/98
Diane J. Koronai 3/24/98 Date:	William L. Baker by Date: 3/24/98
Cindy Kellogg 3/24/98 Date:	K. Kello Date: 3 · 24 - 98
3/24/98 Date:	Date: 3/24/98
Date: 24 III 98	X Anne M. Bowen by Date:
3 25 98	26 March '98