State Engineer's Office

HERSCHLER BUILDING, 4-E CHEYENNE, WYOMING 82002
(307) 777-7354 FAX (307) 777-5451
seoleg@state.wy.us

DAVE FREUDENTHAL
GOVERNOR

PATRICK TYRRELL
STATE ENGINEER

PRELIMINARY OPINION

of

WATER SUPPLY AND WATER YIELD ANALYSIS

for

MEDICINE BOW FUEL AND POWER'S

PROPOSED COAL-TO-LIQUID PLANT AND

SADDLEBACK HILLS COAL MINE

IN CARBON BASIN,

CARBON COUNTY, WYOMING

Prepared By:

Wyoming State Engineer's Office

Ground Water Division

July 2007

THE STATE ENGINEER'S ROLE IN INDUSTRIAL DEVELOPMENT AND SITING

If an applicant for an industrial siting permit plans to construct a facility which will use more than 800 acre-feet (260.7 million gallons) of water per year, the applicant must submit a water supply and water yield analysis to the State Engineer. The State Engineer will then review the analysis and "render a preliminary opinion as to the quantity of water available for the proposed facility" (WS 35-12-108(c)). This preliminary opinion will be made available for public comment and the State Engineer will consider submitted comments in preparing a final opinion. The State Engineer's final opinion will be binding on the Industrial Siting Council. If the State Engineer considers the water supply inadequate for the proposed facility, an industrial siting permit will not be issued.

The State Engineer's review is limited to questions of water supply and water yield. Industrial siting and development statutes specifically prohibit the State Engineer from considering questions of interference or potential impacts to existing water rights (WS 35-12-108(g)). However, the State Engineer may attach conditions and limitations to well permits in order to efficiently administer the underground water statutes (WS 41-3-909), and may require interfering appropriators to reduce withdrawals or otherwise mitigate impacts to other appropriators (WS 41-3-911). Under some circumstances, an applicant for an industrial siting permit may identify an adequate water supply but may not be able to exploit it as planned due to restrictions imposed by the State Engineer. In order to provide clarity to applicants and to other potentially affected appropriators, it is the policy of the State Engineer to include a discussion of the conditions and limitations that are likely to be imposed on the applicant's water well permits in the preliminary opinion.

INTRODUCTION

As part of the application process for an industrial siting permit, Medicine Bow Fuel and Power submitted to the State Engineer's Office (SEO) a "Water Yield Analysis" prepared by URS Corporation, which was received on May 9, 2007. In response to questions from SEO, URS Corporation submitted a revised report, a letter response to specific questions, and a CD-R with lithological and geophysical logs and pumping test information on June 13, 2007. This information forms the basis for this preliminary opinion.

WATER SUPPLY NEEDS

Medicine Bow Fuel and Power plans to construct a coal mine that will produce approximately 3.2 million tons of coal per year and a coal-to-liquids (CTL) plant that will use the coal to produce approximately 13,000 barrels of diesel fuel per day. Each facility is expected to employ approximately 200 people. The estimated water use is 44 gallons per employee per day at the coal mine and 25 gallons per employee per day at the CTL plant, where fewer employees will take showers. Total daily use by employees would be about 14,000 gallons. Annual employee use would be about 5,100,000 gallons. This demand could be satisfied by continuous pumping of 10 gal/min.

Process water requirements for the CTL plant were estimated to be 800 gal/min. No estimates were made of mine or other CTL water needs but URS Corporation determined that a supply of 1,000 gal/min would satisfy all plant and mine needs. This would be about 526 million gallons per year, or 1,600 acre-feet per year. Over the 30-year life of the project, total pumpage would be about 15.8 billion gallons, or 48,000 acre-feet.

POTENTIAL SOURCES OF WATER

There is very little ground water production from the Carbon basin so aquifer characteristics are poorly known. The mine and plant site is in the eastern part of the basin in the Second Sand Creek and Third Sand Creek drainages. Proposed well locations (Table 1) are spread across the eastern portion of the basin, primarily in the west half of Township 21 North, Range 79 West, where the Hanna, Ferris, Medicine Bow, and Lewis formations occur at the surface. The Mesaverde Formation occurs beneath the Lewis Shale. Due to the absence of the Lance Formation and Fox Hills Sandstone, the Mesaverde Formation is underlain directly by Steele Shale. Formations below the Steele Shale are generally too deep to be considered. For example, the top of the Niobrara Formation (bottom of Steele Shale) is at a depth of 3,400 feet in the UUC 43-26 oil well (API# 49-007-21606) on the Big Medicine Bow anticline in section 26, Township 21 North, Range 79 West (http://wogcc.state.wy.us/).

Table 1. Test Well Locations and Proposed Production Well Locations at Medicine Bow Fuel and Power's Proposed Coal Mine and CTL Plant

Well Name	Permit No.	Location	Target Formation
MBFP 33		T22N, R79W, Sec. 33, SESE	Mesaverde
MBFP 3		T21N, R79W, Sec. 3, SWSW	Mesaverde
MBFP 5		T21N, R79W, Sec. 5, SESE	Mesaverde
MBFP 7		T21N, R79W, Sec. 7, SESE	Mesaverde
MBFP 9		T21N, R79W, Sec. 9, SWSW	Mesaverde
MBFP 13		T21N, R80W, Sec. 13, NESE	Mesaverde
MBFP 17		T21N, R79W, Sec. 17, SESE	Mesaverde
MBFP 20		T21N,R79W, Sec. 20, NWSE	Mesaverde
MBFP #20-1	U.W.176934	T21N, R79W, Sec. 20, NESE	Medicine Bow
MBFP 21*		T21N, R79W, Sec. 33, SENE	Mesaverde
MBFP #21-1	U.W. 176937	T21N, R79W, Sec. 33, SENE	Mesaverde
MBFP #21-2	U.W. 178649	T21N, R79W, Sec. 33, SENE	Lewis
MBFP 29*		T21N, R79W, Sec. 33, NESE	Mesaverde
MBFP #29-1	U.W. 176938	T21N, R79W, Sec. 33, NESE	Mesaverde
MBFP 31		T221, R79W, Sec. 33, NENE	Mesaverde
MBFP 2		T20N, R80W, Sec. 2, NENE	Mesaverde

*Test well has already been drilled at this location.
Note: The sequence of section quarters is reversed from Table 1 in URS Corporation's letter of June 12, 2007 so that the smaller quarter is first.

Bartos and others (2006) considered the Hanna, Ferris, Medicine Bow, and Mesaverde formations as aquifers and the Lewis and Steele shales as regional confining units. They reported sparse hydrologic information for the Hanna (transmissivities of 54 to 3,886 ft^2/day at pumping rates of 7 to 23 gal/min) and Ferris formations (transmissivities of 54 to 1,286 ft^2/day at pumping rates of 0.1 to 40 gal/min), 5 yield measurements of 4 to 50 gal/min for the Medicine Bow Formation, and several yield measurements of 1 to 120 gal/min in the Mesaverde Formation. Bartos and others (2006) also repeated the results of 5 drill-stem tests of the Mesaverde Formation in the Washakie and Great Divide basins reported by Collentine and others (1981) which yielded estimates of transmissivities of 0.5 to 9 ft^2/day.

For the Medicine Bow Fuel and Power's water supply and water yield analysis, two test wells were completed in the Mesaverde Formation and one each in the Medicine Bow and Lewis formations near the plant site to evaluate the water supply potential of these units. In both Mesaverde Formation wells, the aquifer is confined with the potentiometric surface at or close to the land surface. Results of the tests reported by URS Corporation are summarized in Table 2. As a result of these tests, URS Corporation identified the Mesaverde Formation as the most prospective aquifer.

Table 2. Results of Aquifer Tests in Test Wells Near Medicine Bow Fuel and Power's Proposed Coal Mine and CTL Plant

Well Name	**Well Depth (feet)**	**Screen (feet)**	**Pumping Rate (gal/min)**	**Transmissivity * (ft^2/day) (gal/day-ft)**	**Target Formation**
MBFP #20-1	782	292-772	5	1.11 (8.3)	Medicine Bow
MBFP #21-1	1898	1261-1808	100	15.63 (117)	Mesaverde
MBFP #21-2	470	214-460	20	0.85 (6.4)	Lewis
MBFP #29-1	2289	1740-2248	90	13.86 (104)	Mesaverde

*Transmissivities were determined using the Cooper-Jacob method in AQTESOLV. URS Corporation also reported results using the Papadopulos-Cooper method. All wells have a casing radius of .42 feet and a borehole radius of .75 feet.

Results for the 2 tests of wells in the Mesaverde Formation were verified using the Theis and Cooper-Jacob (Cooper and Jacob, 1946) equations. The Papadopulos-Cooper solutions reported by URS Corporation demonstrated that casing storage effects are dramatic in both tests. Consequently, Cooper-Jacob solutions for late-time data are more likely to reflect aquifer properties. URS Corporation did not report which time intervals were used for the Cooper-Jacob solutions. Figure 1 shows Theis and Cooper-Jacob fits to late-time data for the MBFP #21-1 test. Because the drawdown was measured in the pumping well, u is very small ($u = r^2S/Tt$, where r is radial distance from an infinitesimally small pumping well, t is the time after pumping started, S is the storage coefficient, and T is transmissivity) and the Theis and Cooper-Jacob solutions coincide. This fit was chosen visually. Fitting a straight line to the 191 to 781 minute data gives a more objective Cooper-Jacob solution of 117 gal/day-ft (15.6 ft^2/day) for transmissivity. Casing storage effects apparently dominate the drawdown curve at times less than about 170 minutes. The objective solution may be less reliable due to the irregularities in the late-time data. Although storage coefficients are required for a Theis fit and may be calculated for a Cooper-

Jacob fit, the actual values determined are unreliable due to uncertainties about the effective radius to the point of measurement. For these calculations the borehole radius of .75 feet rather than the casing radius of .42 feet was used. This assumes 100% well efficiency.

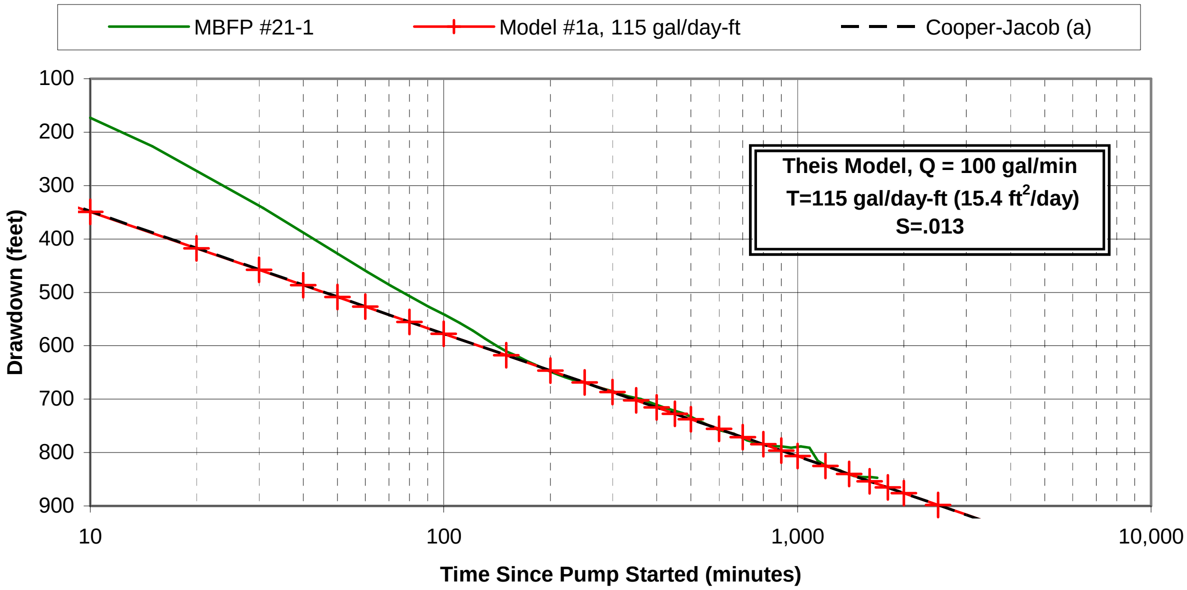

Figure 1. Theis Equation Fit to the Drawdown Data for the Aquifer Test of MBFP #21-1.

Theis and Cooper-Jacob visual fits to the data of the MBFP #29-1 test are shown in Figure 2. Due to apparently prolonged casing storage effects, data earlier than about 600 minutes is not usable. The analytical Cooper-Jacob fit for the 601 minute to 841 minute interval gives a transmissivity of 108 gal/day-ft (14.5 ft^2/day). Irregularities in the late-time data suggest the visual fit may be more reliable.

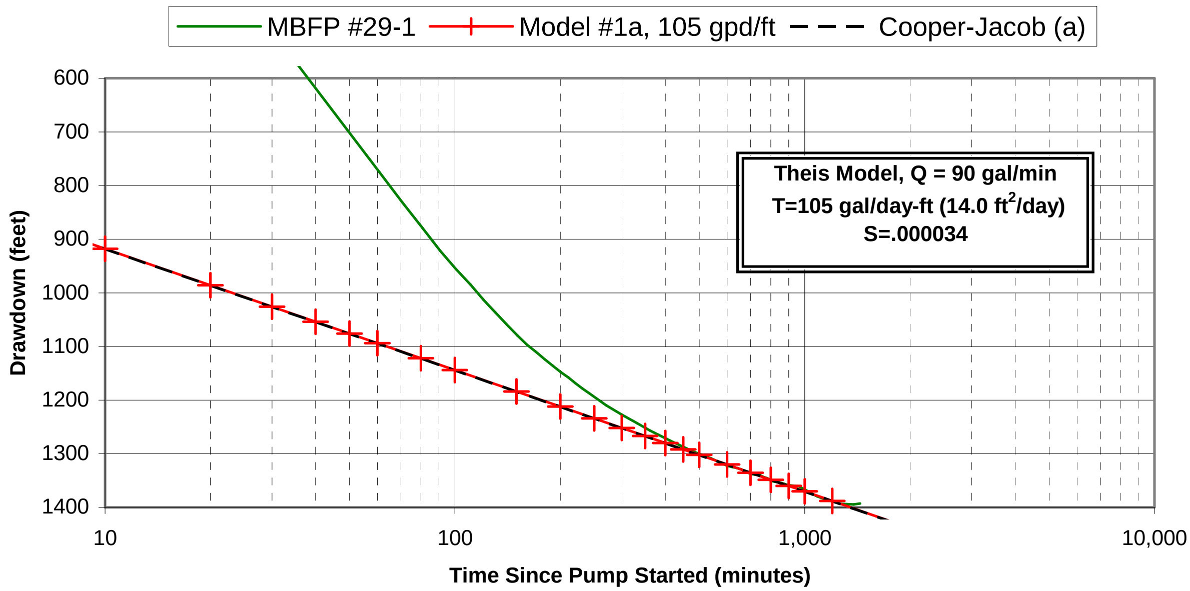

Figure 2. Theis Equation Fit to the Drawdown Data for the Aquifer Test of MBFP #29-1.

The results obtained for the MBFP #21-1 and MBFP #29-1 tests by biasing the fits toward late-time data do not differ significantly from those reported by URS Corporation. In any case, test durations were not long enough to provide reliable estimates of long-term aquifer behavior, to identify leakage from other water-bearing units, or to identify hydrologic boundaries due to faulting, lateral stratigraphic changes, or other causes.

Water quality data summarized by Bartos and others (2006) indicates that water in the Mesaverde Formation has a wide range in concentrations but is generally poor. Data for water coproduced with oil and gas was included in this summary. Of 6 samples collected by the U. S. Geological Survey from water wells with depths less than or equal to 300 feet in the Mesaverde Formation, 5 exceeded the U.S. Environmental Protection Agency's secondary maximum contaminant level for total dissolved solids (500 milligrams/liter) and for sulfate (250 milligrams/liter), and 4 of the 6 exceeded the U.S. Environmental Protection Agency's secondary maximum contaminant level for iron (250 micrograms/liter) (Bartos and others, 2006). As water quality generally deteriorates with depth (Bartos and others, 2006), water produced from the Mesaverde Formation by Medicine Bow Fuel and Power will likely not be considered to be potable.

A flow chart in the Water Yield Analysis (Fig. 2.1) indicates raw water will be treated prior to use in the CTL plant. Presumably, pumped water would also be treated prior to employee use. Design of the water treatment system may be on hold until some of the production wells are constructed. Without any information to the contrary, SEO assumes water quality poses no constraints on the potential water supply for the Medicine Bow Fuel and Power Project.

PROPOSED DEVELOPMENT OF WATER

As shown in Table 1 above, Medicine Bow Fuel and Power intends to obtain its water supply from 12 wells completed in the Mesaverde Formation. Based on the aquifer tests of MBFP #21-1 and MBFP #29-1, an average pumping rate of 90 gal/min is anticipated. Because planned use of 1,000 gal/min is probably an overestimate, two or three of the wells would probably be idle at any one time. This would allow rotation of use to moderate cumulative drawdowns where necessary. Nonetheless, subsequent analysis assumes that all 12 wells pump continuously at 83 gal/min. The plant startup and shutdown dates have not been given but calculations by URS Corporation assumed a project life of 30 years.

AVAILABILITY OF WATER IN PROPOSED SOURCE

Depths and screened intervals for the proposed wells have not been determined. Dips on the east side of the Carbon basin are to the west or southwest so most proposed well locations are down dip from MBFP #21-1. The top of the screened interval is at 1,261 feet in MBFP #21-1 and 1,740 feet in MBFP #29-1. In the original calculations of water supply, URS Corporation assumed 1,200 feet of available drawdown to the top of the aquifer averaged over all the wells. In light of the more recently proposed well locations, this depth is too conservative. Blackstone’s (1993) cross-section of the southern Carbon basin has a maximum depth to the top of the Mesaverde Formation of about 5,200 feet. Blackstone’s (1993) structure contour map has a northeast-trending, down-on–the-west normal fault but this is not shown on his cross-section. The trace of the fault seems to pass close to the locations of MBFP #21-1 and MBFP #29-1. Blackstone’s (1993) work thus suggests depth to the Mesaverde Formation increases rapidly trending westward from the east side of the basin. In the following calculations of water supply, the available drawdown to the top of the Mesaverde Formation is assumed to be 1,800 feet, which is still a conservative estimate (i.e., likely to underestimate water supply).

The volume of water available for extraction from a confined aquifer depends on the available drawdown and the storage coefficient. Storage coefficients for confined aquifers are typically .001 to .00001 (Driscoll, 1986, p. 68). The volume of water that can be extracted from a 1 foot by 1 foot column of Mesaverde aquifer by a 1,800 feet decrease in head is:

1,800 feet x 1 feet^2 x .00001 = 0.018 feet^3 (per ft^2), or
1,800 feet x 1 feet^2 x .001 = 1.80 feet^3 (per ft^2).

The 48,000 acre-feet required over the life of the power plant amounts to 2,091 million cubic feet. The area required to supply that amount of water is:

2,091 million feet^3 / 0.018 feet (per ft^2) = 116,000 million feet^2, or
2,091 million feet^3 / 1.80 feet (per ft^2) = 1,160 million feet^2 .

Circles with radii of 192,000 feet (36 miles) or 19,200 feet (3.6 miles), respectively, have such areas.

This suggests Medicine Bow Fuel and Power may be able to obtain its water supply from the confined portion of the Mesaverde aquifer if the storage coefficient is relatively high. However, a pumping well does not withdraw water from a cylinder, it withdraws water from a cone of depression that progressively steepens closer to the well. For a transmissivity of 104 gal/day-ft (14 ft^2/day) and a storage coefficient of .00005 (comparable to MBFP #29-1), a well pumping continuously at 83 gal/min will experience about 1,800 feet of drawdown at the end of 1 year (assuming a radius of .75 feet). 5,000 feet away from the pumped well, the drawdown would be about 200 feet. For Medicine Bow Fuel and Power to obtain sufficient water, the Mesaverde Formation will have to be dewatered in the vicinity of the pumping wells.

The amount of water available from the Mesaverde Formation once it becomes unconfined is dependent on the thickness and specific yield of the aquifer. Lowry and others (1973) stated that the Mesaverde Group varies from 4,000 feet thick in the west to 2,000 feet thick in the Hanna, Shirley, and Laramie basins. Blackstone's (1993) cross-section shows a thickness of 2,700 to 3,000 feet in the southern Carbon basin. Considering that it would not be possible to dewater the entire formation with widely spaced wells due to the low transmissivity, the thickness of 2,000 feet used in the Water Yield Analysis is reasonable. The specific yield of .05 is also reasonable.

The volume of water available for extraction from an unconfined aquifer depends on the saturated thickness and the specific yield. The volume of water that can be extracted from a 1 foot by 1 foot column of unconfined Mesaverde aquifer by draining 2,000 feet of saturated thickness for specific yields of 0.01 to 0.10 is:

2,000 feet x 1 $feet^2$ x .01 = 20 $feet^3$ (per ft^2), or
2,000 feet x 1 $feet^2$ x .1 = 200 $feet^3$ (per ft^2).

The 48,000 acre-feet required over the life of the power plant amounts to 2,091 million cubic feet. The area required to supply that amount of water is:

2,091 million $feet^3$ / 20 feet (per ft^2) = 105 million $feet^2$, or
2,091 million $feet^3$ / 200 feet (per ft^2) = 10.5 million $feet^2$.

Circles with radii of 5,800 feet or 1,800 feet , respectively, have such areas.

Assuming that drawdown in an unconfined aquifer can be approximated using the Theis equation with the transmissivity and specific yield of the aquifer (it will actually be less than that predicted by the Theis equation due to the delayed yield effect), drawdown after 30 years of pumping continuously at 83 gal/min would be about 1,640 feet for a specific yield of 0.01 or about 1,430 feet for a specific yield of 0.10. Drawdowns 5,000 feet away would be about 60 feet or less than 1 foot, respectively. As the proposed well spacing is generally at least 1 mile, dewatering the Mesaverde aquifer with pumps set below approximately 2,000 feet of saturated thickness would probably yield the needed amount of water. This is in addition to the amount released from the aquifer while it is confined. As the proposed wells are arrayed over the eastern one-third of the Carbon basin, more wells could be drilled to the west if additional water were needed.

Current demands on the water supply in the Mesaverde Formation in the Carbon basin are slight. Although there are several monitor wells, producing water wells are almost nonexistent There is a 5-feet deep stock watering well (Permit No. U.W. 97282) that yields 3 gal/min in the area of outcrop of the Mesaverde Formation in Section 16, Township 22 North, Range 79 West. It is at least 3 miles from the nearest proposed MBFP well and is on the opposite side of the Big Medicine Bow anticline thrust fault. There is a 540-feet deep well (Permit No. U.W. 58146) on the outcrop of the Lewis Shale in Section 36, Township 22 North, Range 79 West. It may bottom in Lewis Shale but there is no lithologic information below 300 feet. This well is also northeast of the Big Medicine Bow anticline thrust. The well is for restrooms at the U.S. Bureau of Reclamation visitor center and its use is probably minimal. There are probably less than a dozen wells in the Carbon basin that are completed in formations shallower than the Mesaverde Formation. Consequently, the Mesaverde Formation is unlikely to lose water due to leakage caused by pumping in shallower formations and the entire stored volume appears to be available to Medicine Bow Fuel and Power. Furthermore, Medicine Bow Fuel and Power would have a sufficient supply even if recharge to the Mesaverde aquifer was non-existent.

YIELD OF PROPOSED SOURCE

Because little is known about the Mesaverde aquifer in the Carbon basin, the two 1-day pumping tests conducted without the benefit of observation wells which would allow determination of the storage coefficient are probably inadequate for reliably predicting long-term well yields. But that is all the data available.

If the aquifer has a transmissivity of about 104 gal/day-ft (14 ft^2/day), a well with available drawdown of 1,800 feet pumping continuously at 83 gal/min will pump down to the top of the confined aquifer in about 1 year for a storage coefficient of .00005, or in about 20 years for a storage coefficient of .001. Consequently, production wells must rely on dewatering part of the aquifer. In that case, wells could pump continuously for the required 30 years as long as the pumps are set below about 1,650 feet of saturated aquifer (for a total well depth on the order of 3,000 feet).

The number of proposed wells is predicated on the ability of the wells to pump at rates of 90-100 gal/min. If some of the wells cannot pump at that rate, additional wells will have to be drilled to make up the shortfall in total production.

In the revised spacing of the proposed wells, most wells are at least one mile apart. Although interference is likely to be on the order of a few hundred feet during pumping while the aquifer is confined, it will probably be substantially less than 100 feet after the transition to unconfined conditions. Because most of the water will be produced during pumping under unconfined conditions, decreases in yield due to interference are probably within the uncertainties of the other calculations.

CONDITIONS AND LIMITATIONS FOR NEW WELL PERMITS

In approving an application to appropriate ground water, the State Engineer may attach conditions and limitations to the use of the well in order to administer the laws, to prevent pollution of aquifers, to prevent the waste of water, and to monitor water resources. The following conditions and limitations are routinely attached to industrial use ground water rights:

- Annual volumetric use will be capped. The cap is typically the anticipated need. For this project, the cap would apply to all wells producing from the target aquifer for the same use rather than to each well individually.
- A flow meter will be installed to measure well production.
- Pumping and static water levels will be measured on a regular basis. The frequency of measurement can be tailored to conform to the anticipated pattern of well use.
- A report of ground water production and water levels will be submitted to the State Engineer annually.

The appropriator can request that permit conditions be modified or waived.

The following conditions and limitations are routinely attached to deep wells that traverse more than one aquifer:

- Water can be produced from only one aquifer. In this case, production would be limited to the Mesaverde aquifer.
- The well will be cased with new casing and the annulus will be cemented from the top of the target aquifer to the land surface. A minimum annulus thickness may be required to ensure a competent cement seal. A cement bond log may be required.

Because little information is available for the Mesaverde aquifer in the Carbon Basin, the following conditions and limitations will ensure that the State Engineer manages the aquifer appropriately and can respond to complaints of interference:

PRELIMINARY OPINION

Based on the information summarized above, it is the preliminary opinion of the State Engineer that sufficient water exists in the Measverde aquifer to supply up to 48,000 acre-feet of water to Medicine Bow Fuel and Power's coal mine and CTL plant over a period of 30 years. Plans to drill 12 production wells in order to obtain a total yield of 1,000 gal/min are reasonable based on the very limited information obtained from pumping tests of two test wells. If well yields are less than the anticipated 90-100 gal/min, additional wells could be drilled.

REFERENCES

Bartos, T.T., Hallberg, L.L., Mason, J.P., Norris, J.R., and Miller, K.A., 2006, Water resources of Carbon County, Wyoming: U.S. Geological Survey, Scientific Investigations Report 2006-5027, 191 p.

Blackstone, D.L., Jr., 1993, Overview of the Hanna, Carbon, and Cooper Lake basins, southeastern Wyoming: Geological Survey of Wyoming, Report of Investigations No. 48.

Cooper, H.H. and Jacob, C.E., 1946, A generalized graphical method for evaluating formation constants and summarizing well field history; American Geophysical Union, Transactions, v. 27, no. 4, p. 526-534.

Driscoll, F.G., 1986, Groundwater and Wells, 2nd edition: Johnson Division, St. Paul, Minnesota, p. 1089.

Lowry, M.E., Rucker, S.J., IV, and Wahl, K.L., 1973, Water resources of the Laramie, Shirley, Hanna basins and adjacent areas, southeastern Wyoming: U.S. Geological Survey, Hydrologic Investigations Atlas HA-471, 4 sheets.

Theis, C.V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of a well using groundwater storage: American Geophysical Union, Transactions, v. 16, p. 519-524.