APPENDIX A

ESTIMATED PUMPAGE RATES FOR SIX DRAINAGE BASINS IN THE POWDER RIVER BASIN, WYOMING

(Source: BLM 2007a.)

Estimated Pumpage Rates for Six Drainage Basins in the Powder River Basin, Wyoming

Introduction

Several areas in the Wyoming portion of the Powder River Basin have been subject to substantial ground water drawdown in coal aquifers due to production of coalbed natural gas (CBNG) which is also called coalbed methane. This report identifies historical rates of water production for six drainage basins (sub-watersheds) in northeast Wyoming. It also predicts average pumpage rates for CBNG wells in the drainage basins for the years 2010, 2015, and 2020. The drainage basins are listed in Table 1. Locations of the drainage basins are shown on a map of northeast Wyoming, Figure 1.

Purpose

In order to model ground water depletion as the projected development of CBNG continues through 2020, it is necessary to develop assumptions of average pumping rates as wells are drilled, produced and abandoned in future years. It has been observed that as the number of wells in a given area are drilled and produced, there is a relationship between the number of wells and the average water production rate per well. The number of wells for a given area (drainage basin a of sub-watershed) was predicted through 2020 and is reported in the Task 2 report (ENSR 2005).

	Drainage Basin	Average Total Depth	Est. Average Well Life	Est. Average EUR in MMCFG
1	Antelope Creek	788	8.0	221
2	Dry Fork Cheyenne	1,725	No data	No data
3	Little Powder	655	7.1	123
4	Upper Belle Fourche	902	6.8	171
5	Upper Cheyenne River	566	6.2	217
6	Upper Powder River	1,291	8.0	177

Table 1 Summary of well statistics for CBNG wells in the six drainage basins reviewed. The average well life and EUR numbers are for wells with first production dates before 2003.

Procedure

The API numbers for all CBNG wells in each drainage basin listed in Table 1 were provided by ENSR Corp. The API numbers were used to identify wells in the IHS Energy well and production databases. Only CBNG well data were retrieved from the databases. Duplicate entries were culled. The number of wells was totaled for each drainage basin by year based on the spud date.

Estimated well life and estimated ultimate recovery (EUR) of coalbed gas for wells which began

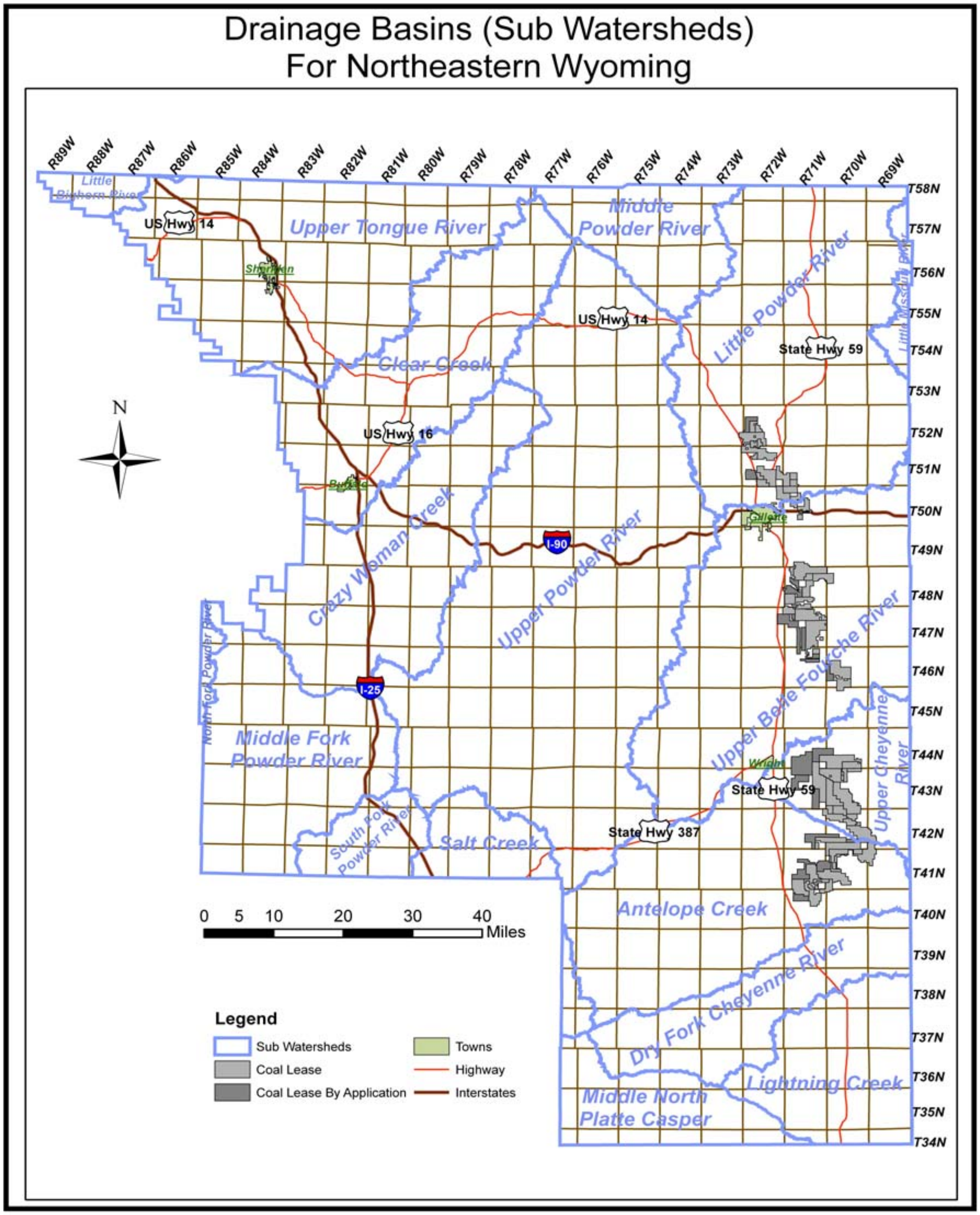

Figure 1. Map of northeast Wyoming showing the locations of drainage basins analyzed in this report.

	Drainage Basin	Estimated Wells	Drilled Wells as % of Projected	Total Withdrawal in Acre Feet	Avg. Well Depth in Ft.
1	Antelope Creek	5,020	26%	21,764	788
2	Dry Fork Cheyenne	1,195	1%	481	1,725
3	Little Powder River	7,191	46%	67,563	655
4	Upper Belle Fourche	10,848	63%	122,726	930
5	Upper Cheyenne River	1,212	50%	26,685	566
6	Upper Powder River	24,930	30%	124,259	1,291

	gpm/mo/ well Jun-Aug06	Decline. Rate Aug05 -Aug06	Est. Pumpage in gpm/well				Remarks
			2005	2010	2015	2020	
1	2.50	29%	3.6	2	2	2	
2	10.57	87%	20.8	5	3	2	Uncertain estimates.
3	2.23	9%	2.5	2	1	1	
4	5.36	-6%	5.1	5	3	1	
5	1.89	28%	2.5	2	2	1	
6	5.33	-6%	5.0	5	4	2	

Table 2. List of the drainage basins with estimated water pumpage rates in five year increments. The number of projected wells is the total number of wells projected to be drilled by 2020. The percentage indicates the number of wells that have been drilled as of October 2006. Data are compiled from the IHS Energy production and well databases. The number of wells projected to be drilled by 2020 was obtained from a 2003 study by ENSR Corp. The 2005 pumpage rate was averaged from the 2005 monthly production figures in IHS Energy's historical database.

production before 2003 were calculated. Calculations were based on averaged production rates. Wells with first production later than January 1, 2003 were not used because there was considered to be too great a chance that gas production had not reached the decline portion of the production curve. If gas production was not declining then the exponential decline equation would not accurately predict the remaining reserves, thus making the EUR calculation too low. Wells which had not produced since September 2005 were considered to be depleted. No further reserves were credited to those wells. Weighted average cumulative production from the depleted wells, combined with estimated ultimate gas recovery (EUR) for wells which were still producing were used to calculate an average EUR for wells in five of the six drainage basins. The average well life and EUR were not calculated for the Dry Fork Cheyenne drainage basin due to insufficient data. An exponential decline rate of 40 percent and an economic limit of 10 MCFG/day were used in the calculations. Results are shown in Table 1.

Monthly production data were also retrieved for each drainage basin. Cumulative production histories for each drainage basin were compiled and graphs drawn (figures 5 through 10). Each drainage basin listed in Table 1 was individually evaluated and future pumpage rates were predicted. Nominal pumpage rates were used. The nominal pumpage rate assumes every well produced every day of the month in which there is recorded production. The actual pumpage rate, which was calculated but not used, is a measure of the actual water production rate based on the days a well was active.

This report uses various units of measurement. There has been an attempt to relate water and gas production rates and the ratios between them in units that are appropriate and relate to the disciplines of people who may use this report The relationships between these units are listed in Table 2.

Study Area: T. 47-48 N., R 72 W. (sometimes referred to as the "Fairway Area" or the "Marquis-Lighthouse" area) Campbell County, Wyoming was the first large area with fully developed CBNG production. The producing horizon is the Wyodak-Anderson coal interval. The Wyodak-Anderson interval is the main coalbed gas producing interval on the east side of the Powder River Basin, and it is the main coal producing interval in all the large coal mines in the eastern Powder River Basin. Because the Fairway area has been fully developed, it was selected as a study area in an attempt to determine how pumpage rates vary compared to other production data. Figures 3a, 3b, and 3c show the average nominal pumpage rate in gpm/well compared to several other factors. Figure 4 shows the relationship between these two rates. The nominal rate was used because it requires less information to calculate and closely approximates the actual rate.

1.00	gallons/minute
34.3	barrels/day
1,035	barrels/month
0.133	acre feet/month
0.00223	cubic feet/second

Table 2. Rate equivalents assuming 30.4 days/month. One barrel is 42 gallons.

Data from the study area are displayed in Figures 3a, 3b, and 3c, and show that other data and ratios do not give a clear indication of future average pumpage rates. Parameters such as total gas production and average gas production per well do not begin to decline until several months or years after the average pumpage rate starts declining. Figure 4 is a graph of pumpage rates and well numbers for the entire Wyoming portion of the Powder River Basin. Notice that even on a basin scale pumpage rates began declining when the number of wells was relatively low. When about six percent of the total estimated wells for the Powder River Basin had been drilled, production began declining in a more of less regular pattern. This allowed future pumpage rates to be forecast.

Evaluation of Drainage Basins

An evaluation and discussion of each drainage basin is given below. Historical and estimated future pumpage rates for each drainage basin are listed in Table 2. Historical data are presented graphically in figures 5-10. The average pumpage rates for five of the six drainage basins have stabilized between two and five gallons per minute. An estimate of future rates based on projected pumpage rate declines is not needed for any of these five drainage basins. The Dry Fork Cheyenne drainage basin has few producing wells and pumpage rates have not

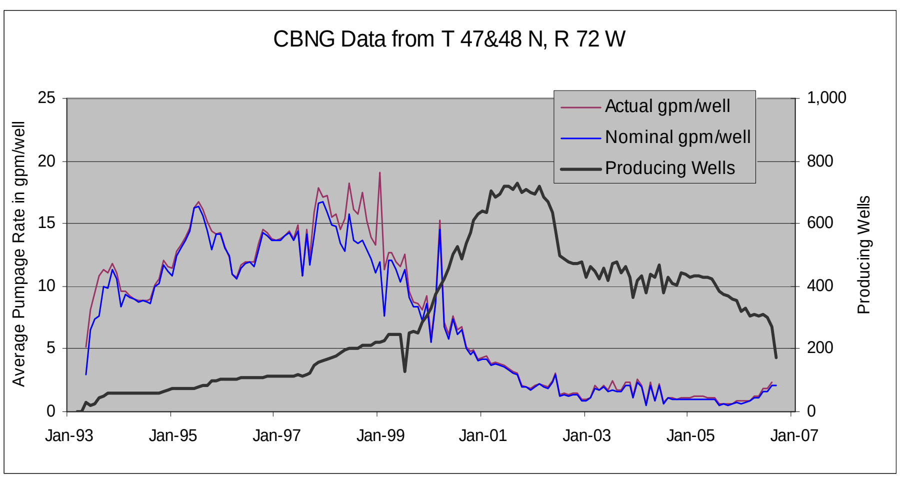

Figure 2. This shows a comparison of the actual and nominal pumpage rates in the study area. The nominal rate was used because it requires less data to calculate.

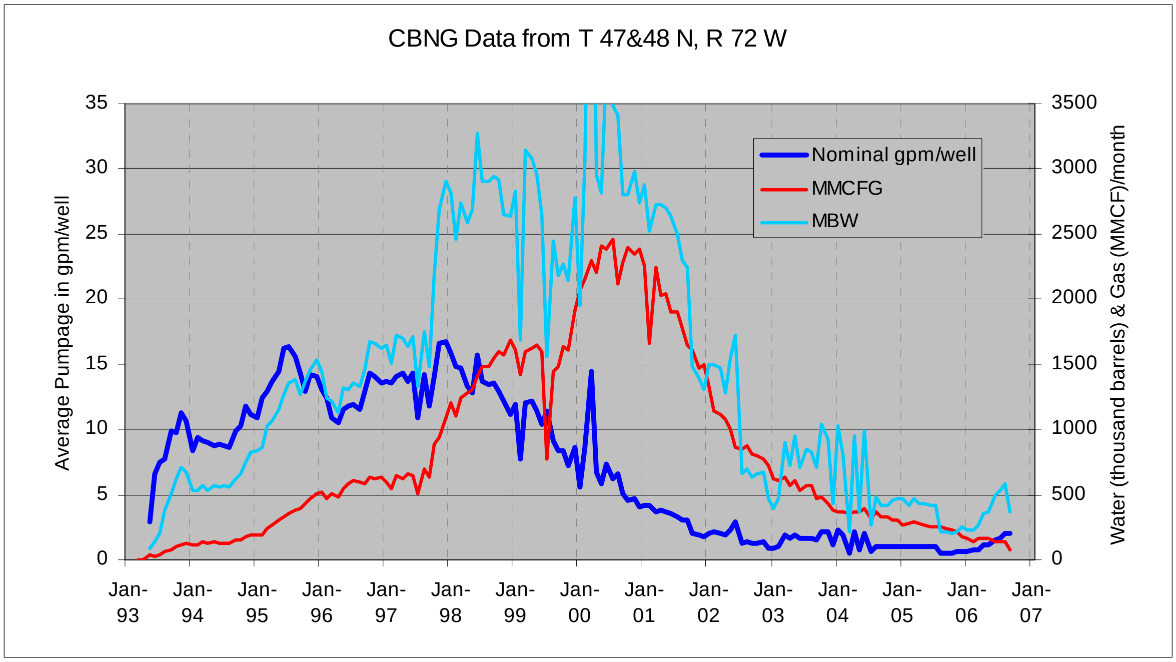

Figure 3a. Monthly data from CBNG wells in the Fairway area. Notice that the average nominal pumpage rate began to decline in a more or less predictable way before either total water production or total gas production began to decline. Data are from the IHS Energy production database.

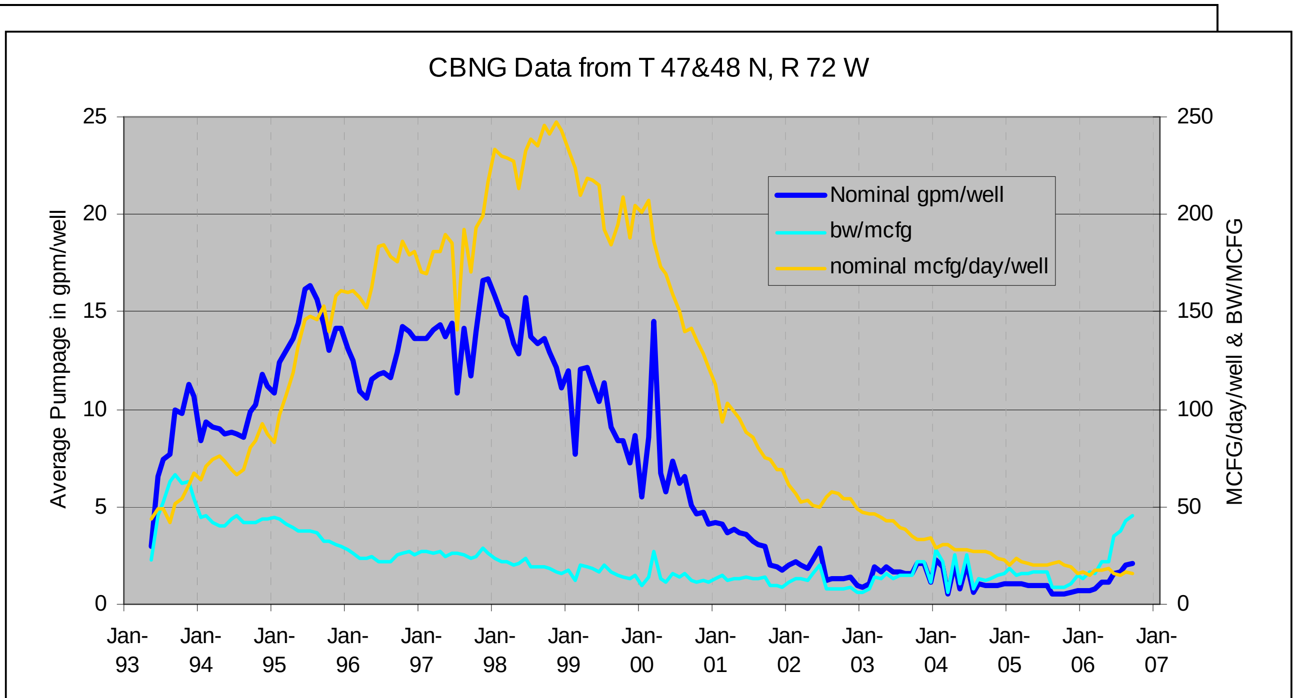

Figure 3b. Monthly data from CBNG wells in the Fairway area. Notice that the average nominal pumpage rate began to decline before the average per well gas production started declining. The water/gas ratio began declining early and appears to have little relationship to the average pumpage rates. Data are from the IHS Energy production database.

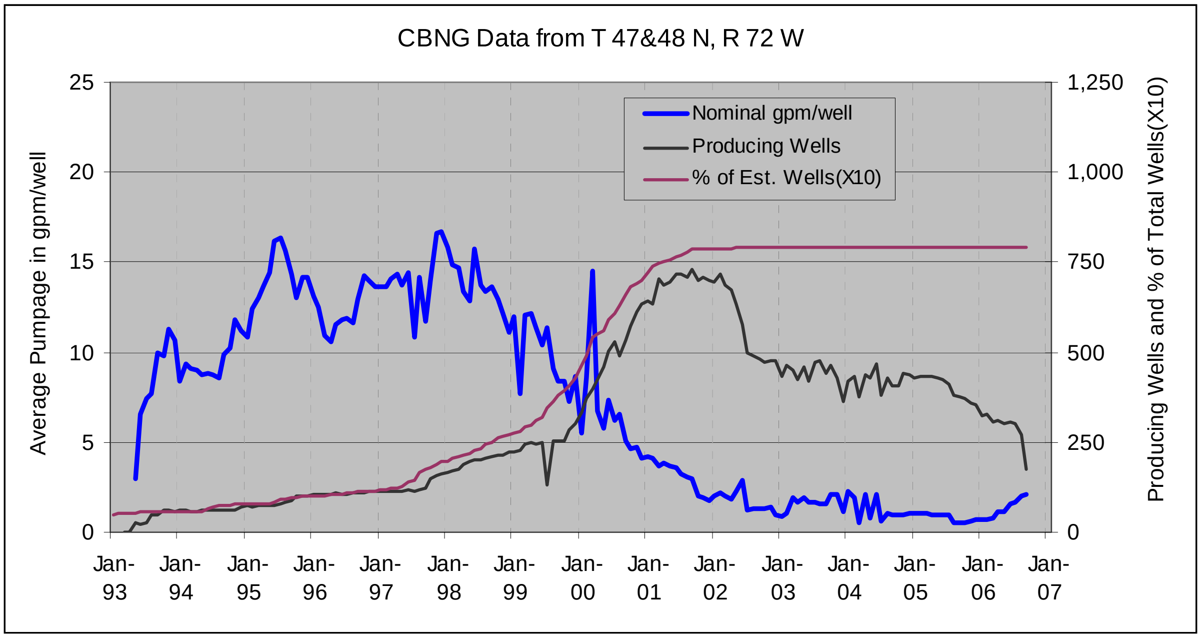

Figure 3c. Monthly data from CBNG wells in the Fairway area. Notice that the average nominal pumpage rate began to decline as the number of productive wells was increasing. Also notice the average pumpage rate began declining when about 20 percent of the total predicted wells had been drilled. The total predicted number of wells (1,104) was calculated by the author and is based on well spacing authorized by the WOGCC. Data are from the IHS Energy production database.

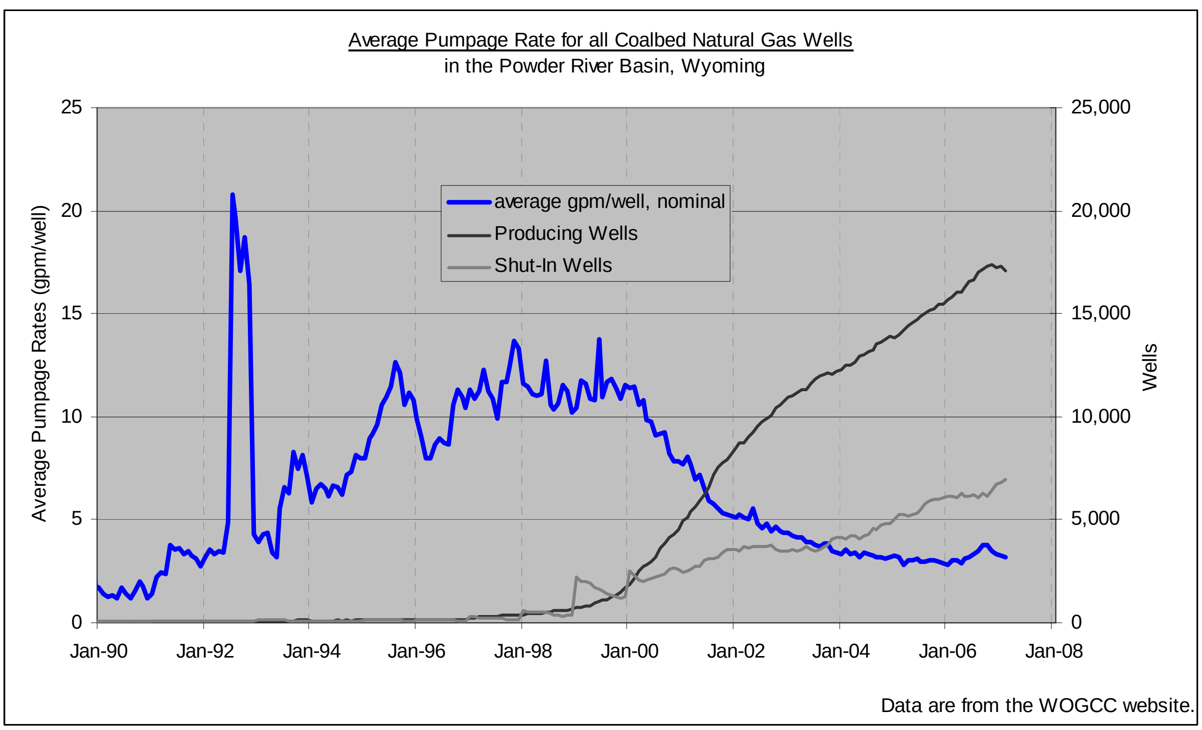

Figure 4. Average nominal pumpage rate for all producing coalbed natural gas wells in the entire Powder River Basin, Wyoming.

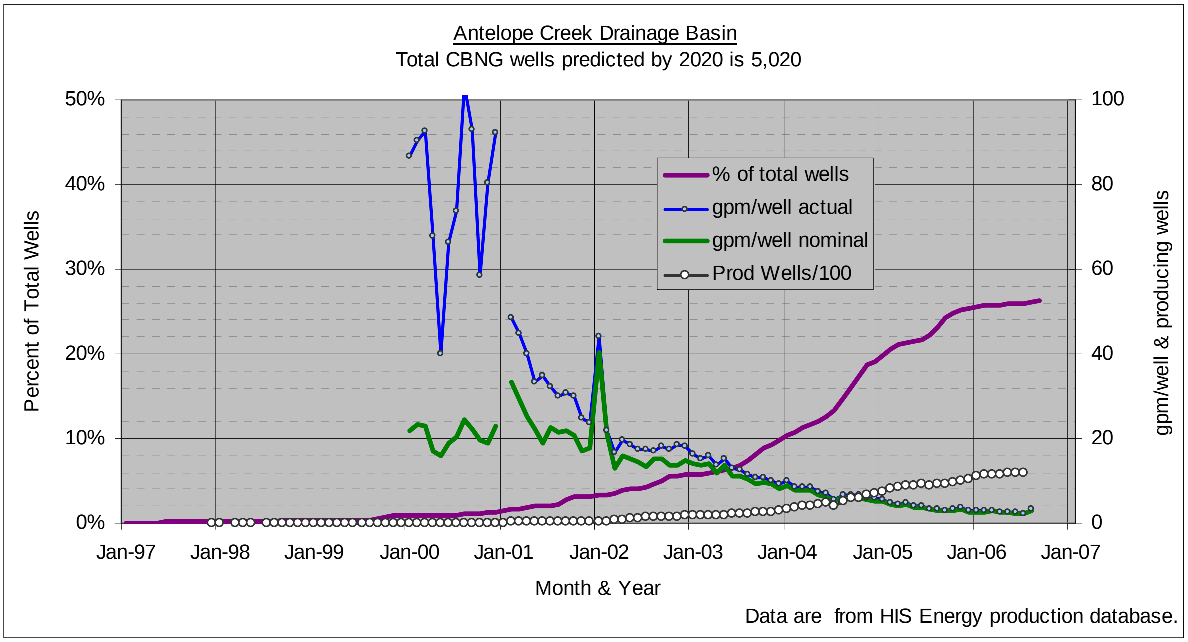

Figure 5a. Historical water production from the Antelope Creek drainage basin. Water production has been continuous since 1998. Historical production data from September 2006 indicate water production is 3.0 gallons per minute per well. The number of producing wells was divided by 100 so the data would plot on the graph.

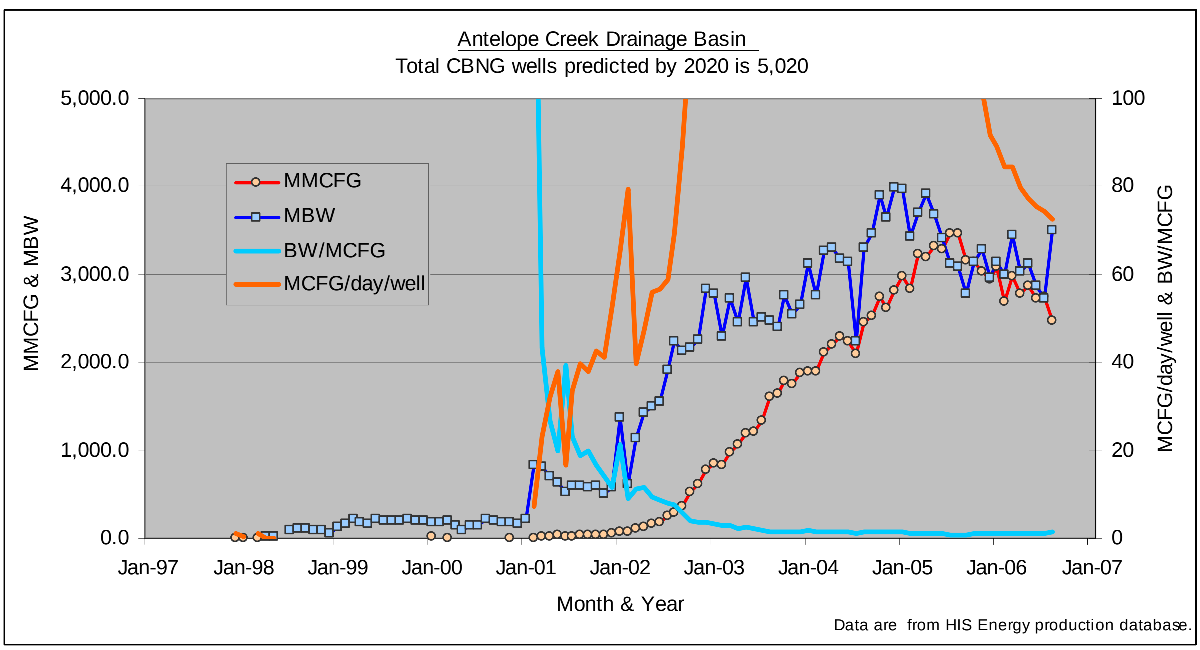

Figure 5b. This graph shows historical gas and water production, and average per well gas and water production for the Antelope Creek drainage basin. During January 2006 – August 2006 water production from the drainage basin averaged 401 acre feet/month.

progressed to a point where a projection can be calculated with much certainty.

Antelope Creek Drainage Basin: Water production began in 2000. Nominal pumpage rates peaked at 40.5 gpm/well in January 2002 (Figure 5a). Data from July 2006 indicated the average pumpage rate was 2.2 gpm/well which was 41 percent less than a year earlier. The average per well gas rate declined at an annual rate of 15 percent during June-August 2006 (Figure 5b). The gas rate is still well above the economic limit (about 10 MCFG/day/well) and the decline appears to be moderating. This suggests that there will not be a large decrease in the number of producing wells in the next few years. Therefore it should be expected that the average pumpage rate will continue to slowly decline even though there was an abrupt increase in August 2006. As the number of producing wells declines the pumpage rate may increase slightly before again declining.

Through August 2006 a total of 21,764 acre feet of water had been produced from the Antelope Creek drainage basin. During August 2006, 451 acre feet of water were produced. Only 26 percent of the total estimated wells had been drilled through August 2006. Because such a low percentage of the estimated total wells have been drilled, it is anticipated that the average pumpage rate will remain at about 2 gpm/well through 2020.

<u>Dry Fork Cheyenne Drainage Basin:</u> This drainage basin is in the early stages of development. Data are insufficient to determine with any degree of certainty what pumpage rates will be at specific future times. Water production began in 2004 and has probably not yet stabilized (Figure 6a). At the end of August 2006, only 14 wells of an estimated 1,195 total ultimate wells had been drilled. There is no reported gas production. There may not be a stabilized pumpage rate for at least a few years. Existing wells produce from the Pawnee coal which is several hundred feet deeper than the main producing coal in the eastern Powder River Basin.

The average pumpage rate in 2005 was 21 gpm/well. The pumpage rate in August 2006 was 9.5 gpm/well. Estimates of future pumpage rates for this drainage basin contain substantial uncertainty. If water production from the Dry Fork Cheyenne drainage basin is similar to most other drainage basins examined in this review, pumpage rates may remain high and erratic for at least a few years then decline in a somewhat predictable pattern to approximately 5 gpm/well after five to fifteen years from the onset of production. Estimates of approximately 5 gpm/well

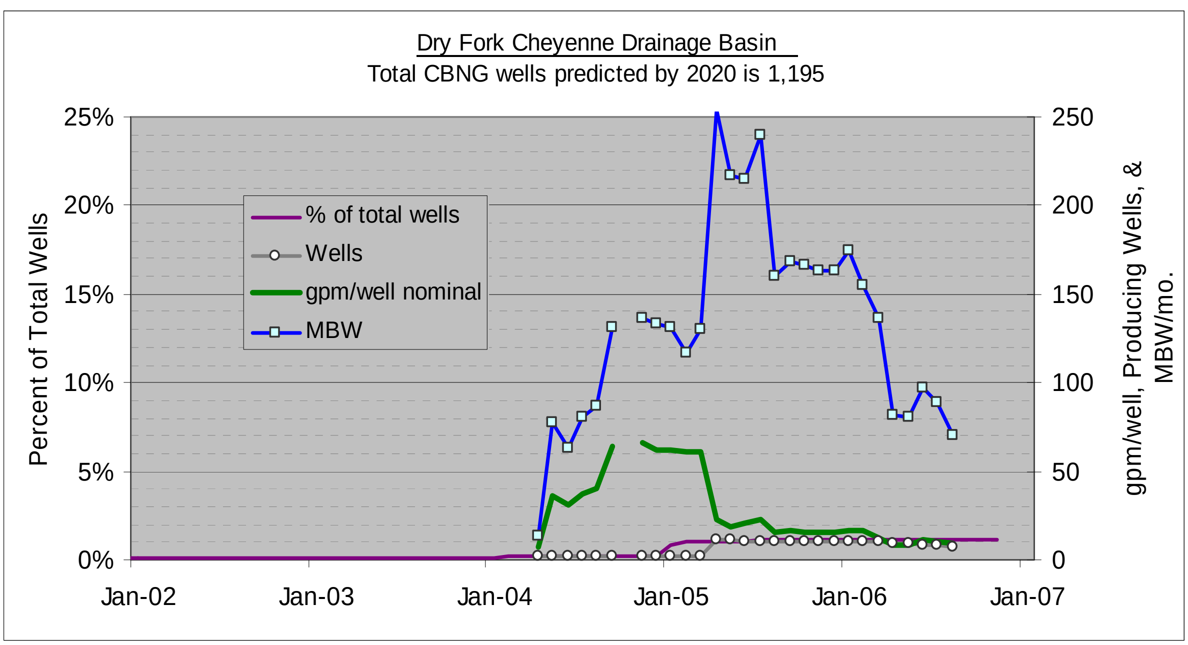

Figure 6a. Historical water production from the Dry Fork Cheyenne drainage basin. Water production began in 2004. There is no recorded gas production for this drainage basin. The most recent available data indicate water production is 9.5 gallons per minute per well.

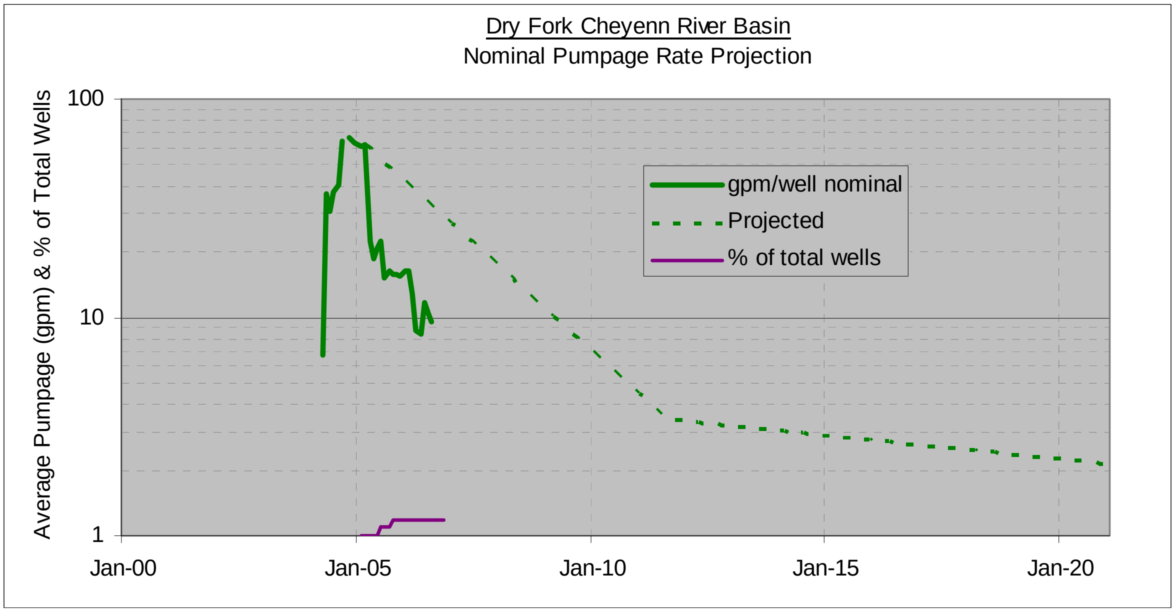

Figure 6b. This figure shows a two stage exponential decline to project future average pumpage rates. An initial rate of 45 percent/year was used until the average pumpage rate reached three gallons/minute. Then the decline rate was changed to 5 percent/year. This projection should be used with caution because fewer than two percent to the projected total wells have been drilled. Production data are from the IHS Energy production database.

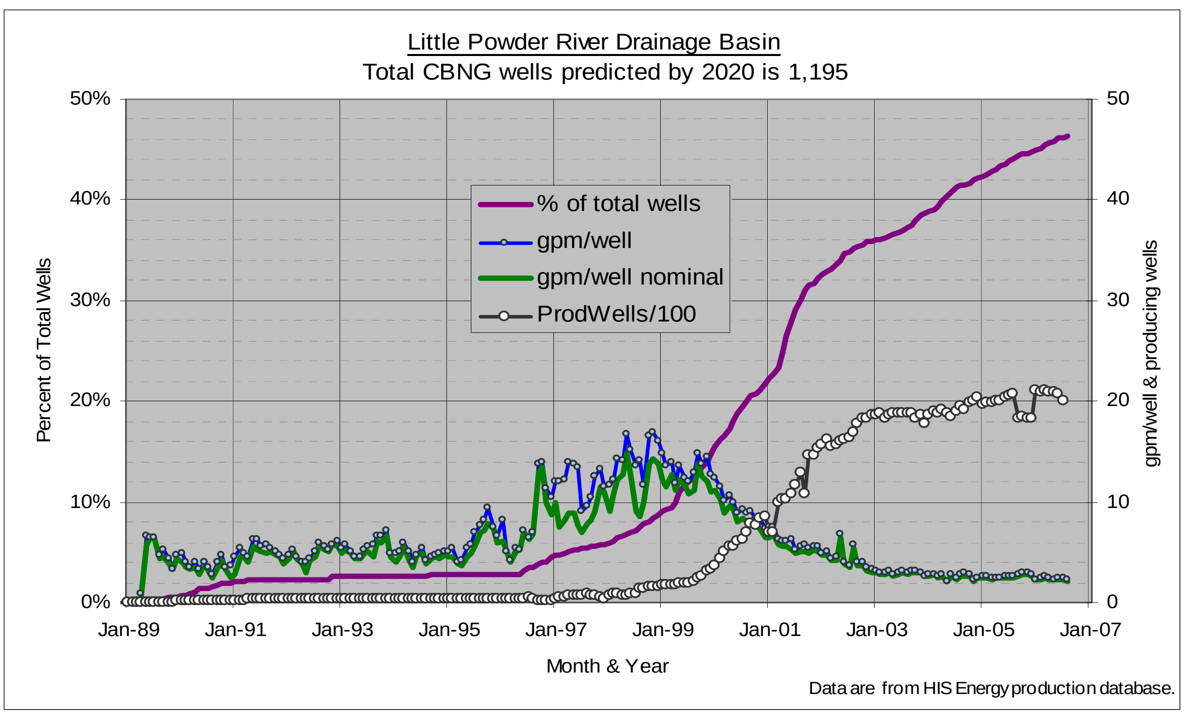

Figure 7a. Historical water production from the Little Powder River drainage basin. Water production has been continuous since 1989. The most recent available data indicate water production is 2.3 gallons per minute per well. The number of producing wells was divided by 100 so the data would plot on the graph.

for 2010, 3 gpm/well for 2015, and 2 gpm/well for 2020 are reasonable based on the available data from other drainage basins. As of September 2006 only about one percent of the estimated total wells had been drilled, therefore these estimates contain considerable uncertainty and may be significantly higher or lower than estimated. They should be used with great caution.

One might try to draw an analogy to the Upper Powder River drainage basin. Pumpage rates in the Upper Powder River drainage basin began declining in May 1999 when less than one percent of the predicted total wells had been drilled. However, the number of producing wells increased from six in May 1999 to almost 1,000 (eight percent of estimated total wells) two years later, and to over 4,000 (28 percent of predicted total wells) by May 2006. Dry Fork Cheyenne drainage basin shows a very different pattern of development. Average pumpage rates began declining in April 2005 when there were only 11 producing wells (one percent of the predicted total). Eighteen months later the number of producing wells had decreased by about half. It is unlikely that the pumpage rates have stabilized. However, if they have, Figure 6b was drawn to show a projection of future rates even though there is great uncertainty. The reader is urged to use Figure 6b and predicted future pumpage rates with great caution.

<u>Little Powder Drainage Basin:</u> Production began in December 1987 and has been continuous since then. Pumpage rates were generally below 6 gpm/well until 1996 when they began increasing to a maximum of 14 gpm in 1999 (figures 7a and 7b). Rates then decreased to the current 2 gpm. The average pumpage rate during August 2006 was 2.3 gpm/well. Total

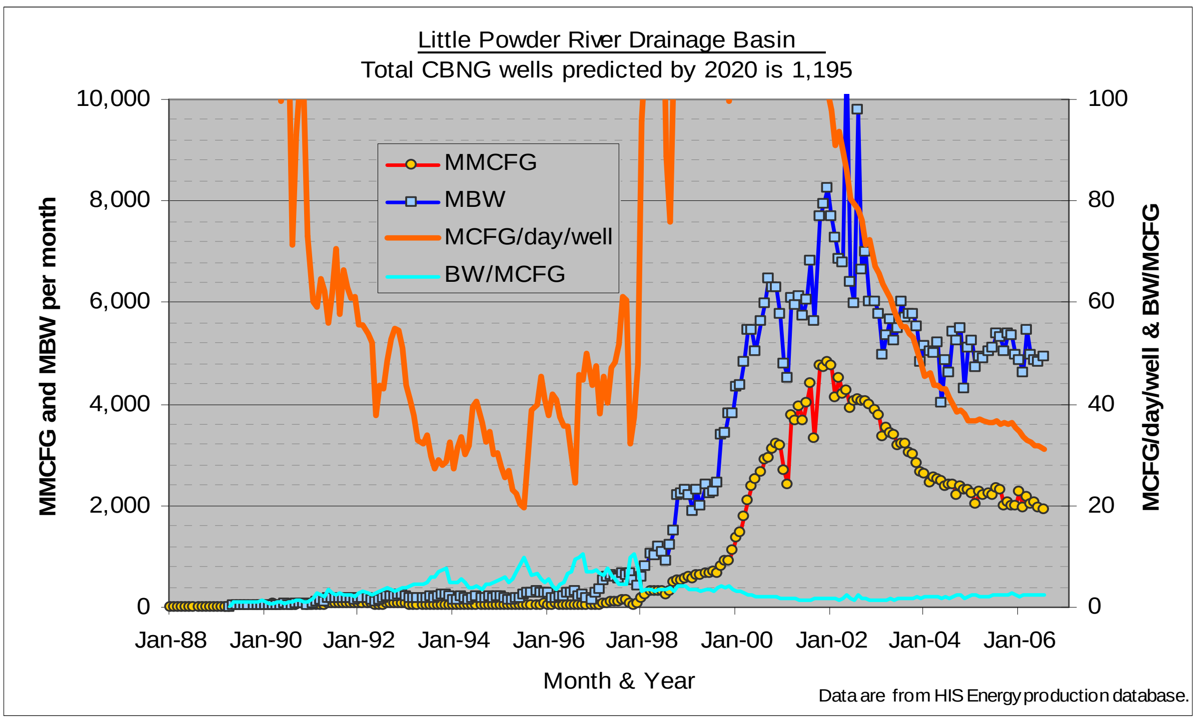

Figure 7b. This graph shows historical gas and water production, and average per well gas and water production for the Little Powder River drainage basin. During July 2004 – July 2006 total water production from the drainage basin has averaged 684 acre feet/month. The average gas production rate is declining 17 percent/year.

monthly water production began a rapid increase in January 1997, and gas began a rapid increase one year later. Both reached a maximum in 2002 then declined. Water production from the Little Powder drainage basin is currently averaging about 254 acre feet per month. The average gas rate per well is currently 34 MCFG/day and declining 17 percent per year. These data are shown graphically in figures 5a and 5b.

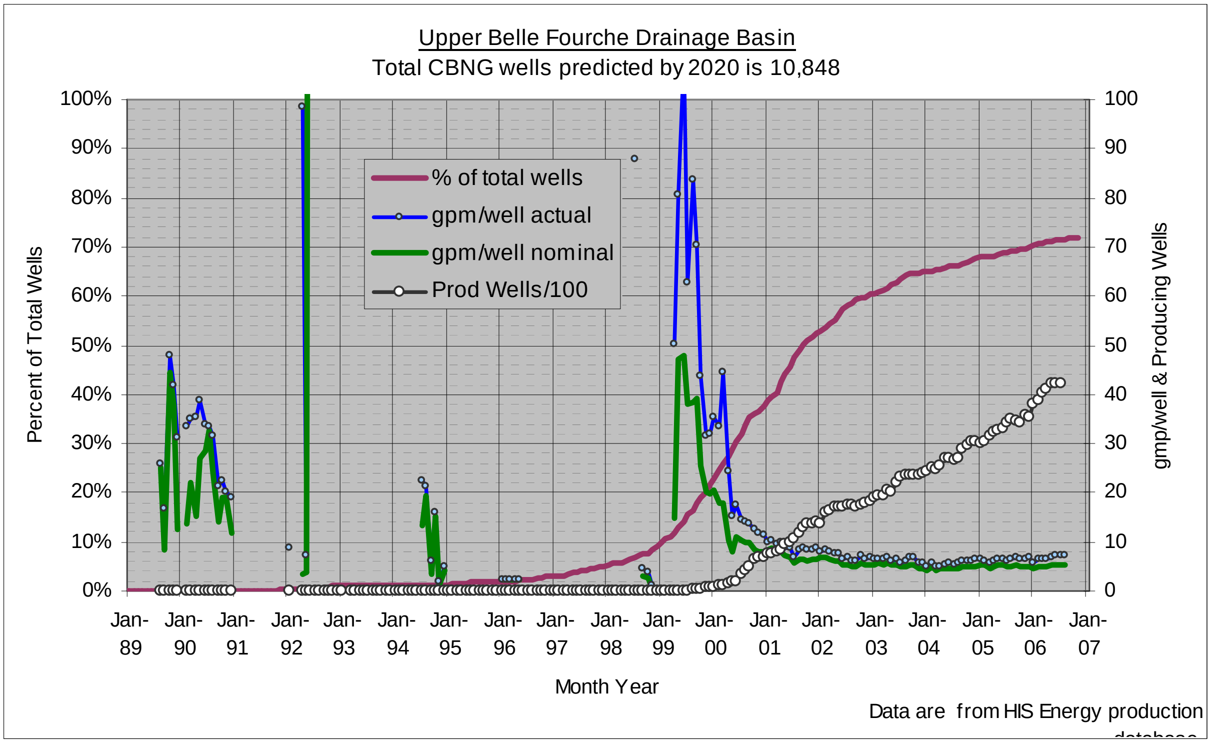

Figure 8a. Historical water production from the Upper Belle Fourche drainage basin. Production appears to be stable at four to six gpm/well. The percent of estimated total wells was modified to eliminate the numerous stratigraphic tests drilled before 1998.

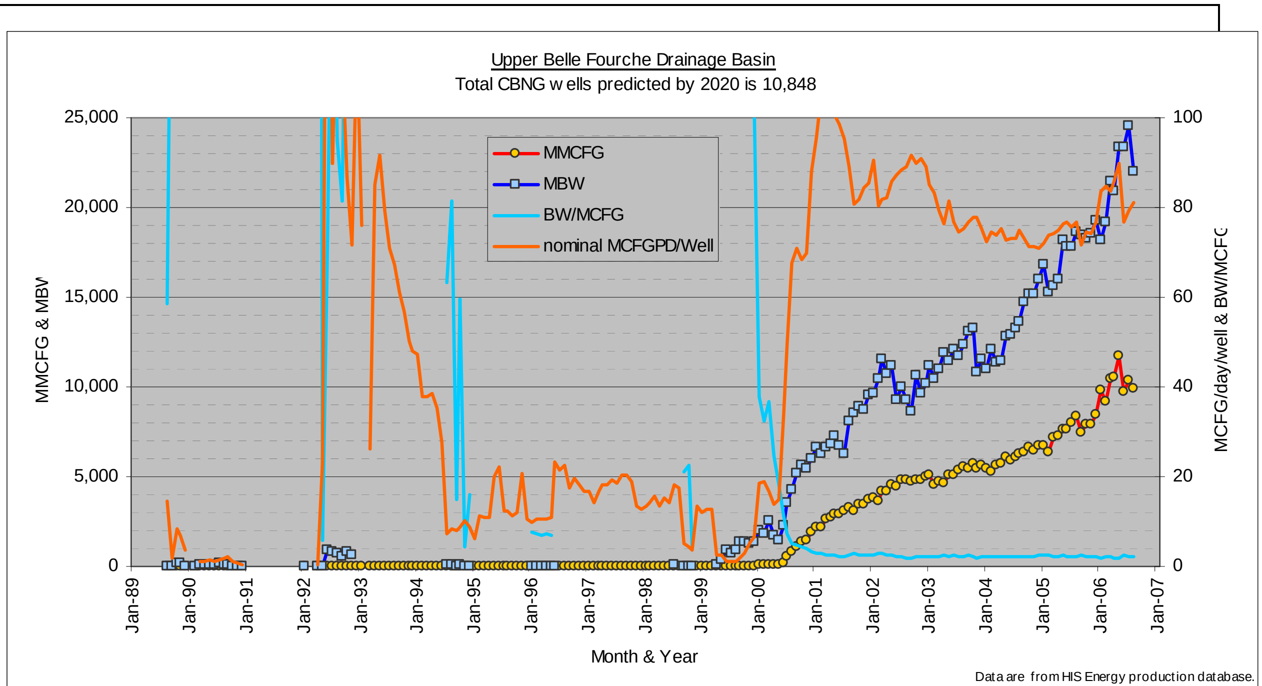

Figure 8b. Historical gas and water production, and average per well gas and water production for the Upper Belle Fourche drainage basin. During 2002-2006 per well gas and water production has remained relatively constant even though total gas and water production has increased. Note that gas production per well has not declined significantly since January 2002.

It is anticipated that the average per well pumpage rate will be 2gpm/well in 2010 then decline to 1 gpm/well in 2015 and remain at 1 gpm/well in 2020.

Upper Belle Fourche Drainage Basin: The area produced water and CBNG sporadically from 1989 to 1992, and continuously since 1992. There is no record of water production during extended periods before 1999 (see figures 8a and 8b). The area is still being developed as evidenced by the increasing number of producing wells and increases in the production rates for both gas and water. Although water production is still increasing, the average pumpage rate peaked in 1999 then declined, and has been stable at about 5gpm/well since 2002. Also, the average gas rate per well is remaining more or less steady at 80 MCFG/day/well. It is anticipated that water pumpage rates will remain stable through 2010 as more wells are drilled. As gas and water production decline, pumpage rates are anticipated to decrease to about 3 gpm/ well in 2015 and to about 1 gpm/well in 2020. As of August 2006, 72 percent of the estimated 10,848 wells had been drilled.

Upper Cheyenne River Drainage Basin: The first wells were drilled in 1994 and water production began in 1997. Water production peaked at 40 gpm/well in July 1998. It has declined in a predictable pattern since January 2001 when 29 percent of the total estimated wells had been drilled (figures 9a and 9b). The pumpage rate declined at a nominal rate of 12 percent from August 2005 to August 2006. However, the average gas production rate is declining about 40 percent annually. Many wells will probably reach an economic limit in the next few years. In August 2006 water production was 1.9 gpm/well. Figures 3a and 3b show water and gas production and pumpage rates for the upper Cheyenne River drainage basin. The number of producing wells has declined steadily since March 2005. As of August 2006, only 50 percent of the estimated 1,242 wells had been drilled. A total of 26,685 acre feet of water has been produced from the Upper Cheyenne River drainage basin.

It is estimated that the number of producing wells will continue to decline in the short term, and that pumpage rates will remain more or less steady at 2 gpm/well until 2015 then decline to 1 gpm/well by 2020. The sharp decline in average per well gas production indicates that many new wells will be needed within a few years if production from this drainage basin is to be sustained. If numerous additional wells are not drilled, continued decline should be expected.

Upper Powder River Drainage Basin: Water and gas production first occurred in 1989 and was intermittent until April 1999. Before April 1999 average water rates were erratic. Although short term water rates were very high the available data indicates less than 1,000 acre feet of water had been produced by April 1999. As of August 2006 about 124,000 acre feet have been had been produced.

When continuous production began the number of producing wells increased rapidly from five in April 1999 to 165 in April 2000. Average per well water production decreased rapidly from a nominal rate of 55 gpm in May 1999 to 10 gpm in April 2000 (see Figure 10a). Average water production continued to decline to 5.2 gpm/well in June 2002, then remained relatively constant (average 5.0 gpm/well) through August 2006. Although the decline rate was high water production rates began to form a more or less predictable pattern in May 1999 when less than one percent of the estimated total wells had been drilled. This number is very low compared to other drainage basins and may suggest that the number of total wells predicted is too high. During the time interval when average per well water production remained relatively steady, the number of producing wells more than doubled, increasing from 1,726 in June 2002

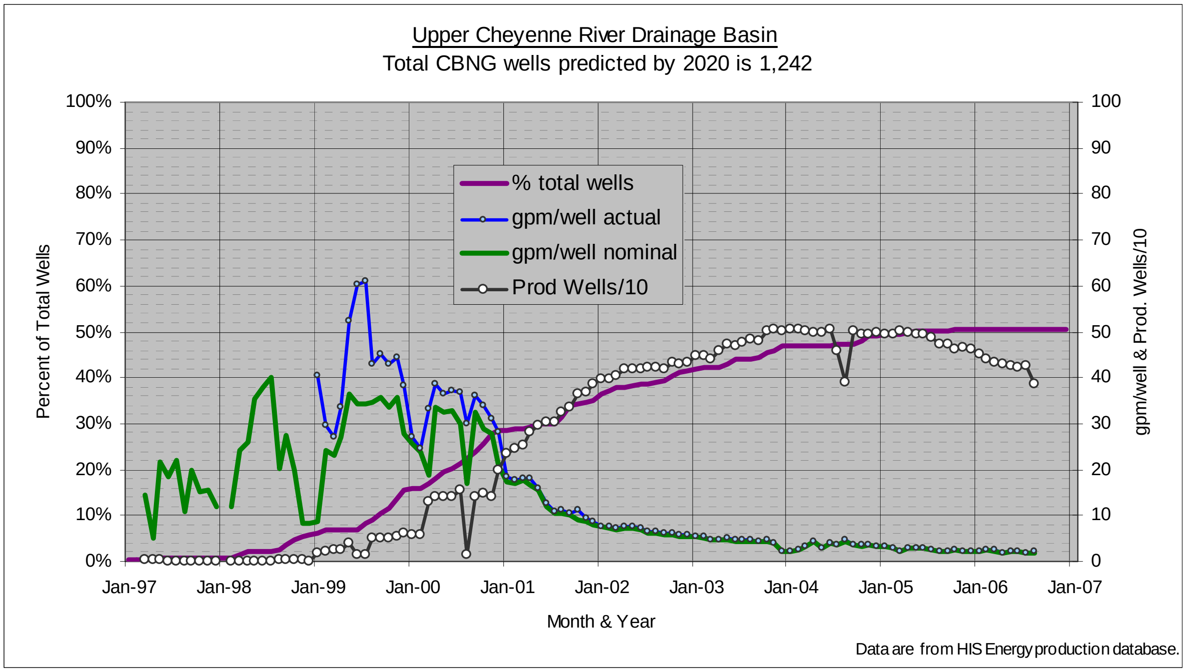

Figure 9a. Historical water production from the Upper Cheyenne River drainage basin. Production declined at a nominal rate of 29.3 percent from Jan-02 through Aug-06, and at a rate of only 11.5 percent from Sep-05 through Aug-06. The number of producing wells was divided by 10 so the data would plot on the graph.

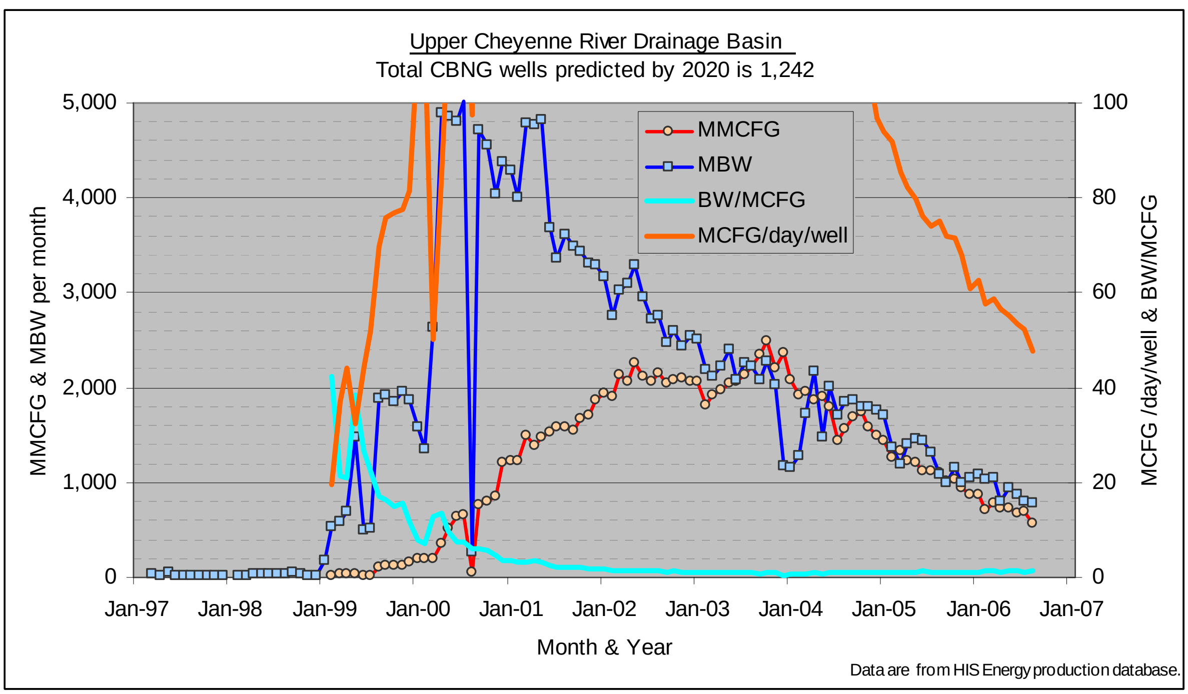

Figure 9b. Historical gas and water production, and average per well gas and water production for the Upper Cheyenne River drainage basin. Both water and gas production are declining rapidly. Average per well gas production is declining 46 percent per year.

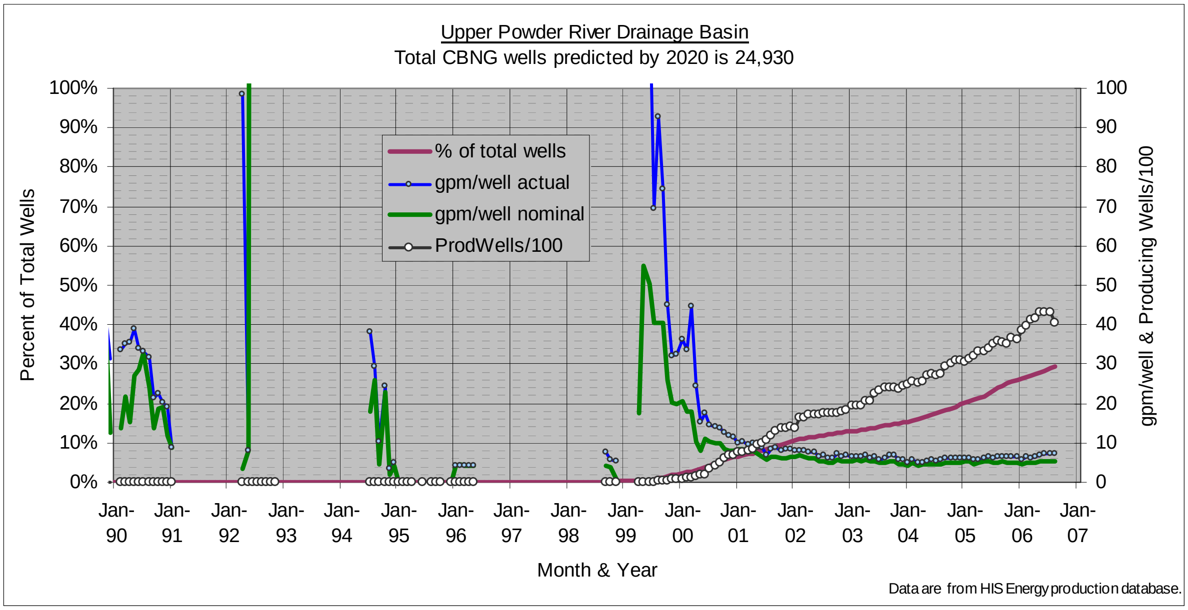

Figure 10a. Historical water production from the Upper Powder River drainage basin. Production was intermittent from 1989 to 1999. Nominal water production rate declined from 55 gpm in May 1999 to 5 gpm in June 2002 and has held steady since then. The number of producing wells was divided by 100 so the data would plot on the graph.

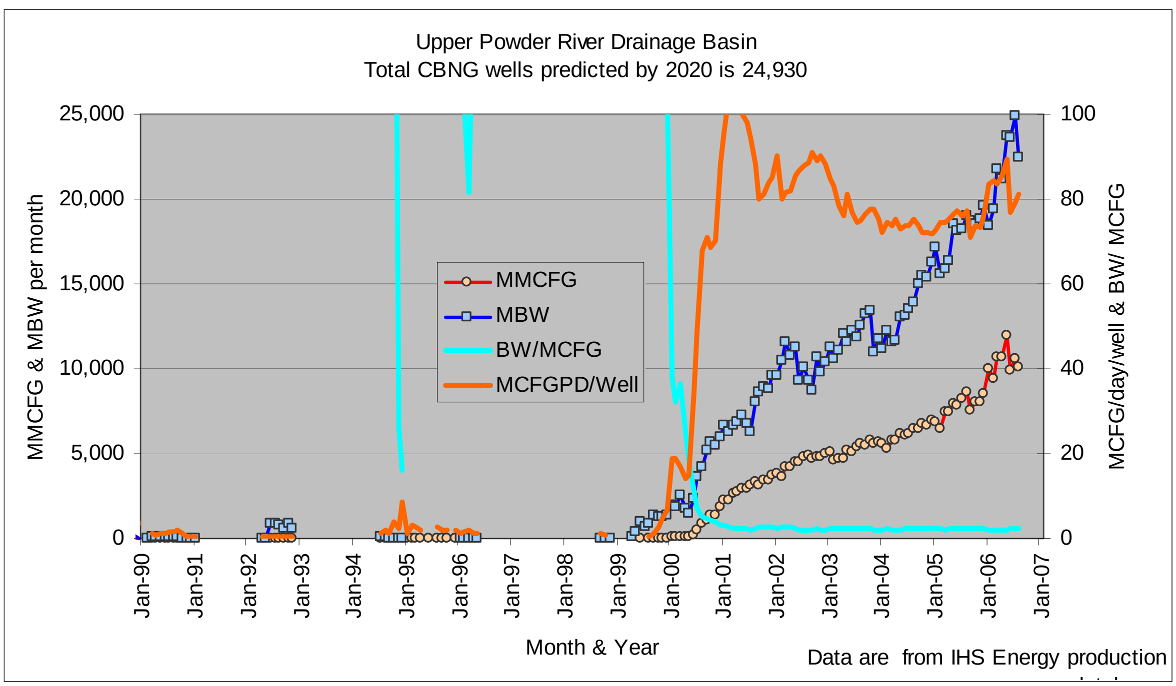

Figure 10b. Historical gas and water production, and average per well gas and water production for the Upper Powder River drainage basin. During 2001-2006 per well gas production has remained relatively constant even though total gas production has increased. Note that gas production per well has not yet begun to decline significantly.

to 4,036 in August 2006. It is interesting to note that during 2000 when the average gas production per well increased about ten fold, water production declined by half in a predictable pattern. The average gas production rate held relatively steady averaging 79 MCFG/day/well from September 2001 – August 2006 (see Figure 10b).

The number of producing wells will eventually stop increasing and begin to decline due to wells being shut-in because of low water and/or gas production rates. When this occurs, perhaps before, the average water production rate will almost certainly begin to decline. It is anticipated that the water production rate will hold steady to about 2010 then decline to approximately 4 gpm/well by 2015 and 2 gpm/well by 2020. This would be a 14 percent annual decline rate from 2015 to 2020.

Summary

Water and CBNG production data from the six drainage basins listed in Table 1 is variable and sometimes erratic. CBNG production and ratios of gas and water are not good indicators of average per well water pumpage rates within a drainage sub-basin. Pumpage rates often decline when the number of producing wells and gas production are increasing. By the time producing CBNG wells are about 10 to 20 percent of the total estimated number of wells that will be drilled pumpage rates are usually stable enough so that future rates can be predicted with reasonable certainty. In some areas pumpage rates stabilized earlier in the development history, however the lower levels of development may produce more uncertainty in estimates of future pumpage rates.

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BLM, Wyoming Reservoir Management Group-Wyoming State Office

Acronyms and Glossary

Acre feet — The amount of space occupied by an area of one acre (43,560 square feet) one foot deep. Water volumes are sometimes measured in acre feet.

Actual pumpage rate — As used in this report is the actual rate of water production from a well based on the actual days the well produced during the month. For example, if a well produced for only 10 days during the month of June and produced a total of 1,500 barrels of water, the actual pumpage rate would be 150 barrels per day (4.38 gallons/minute) but the nominal pumpage rate would be 50 barrels per day (1.46 gallons/minute).

API number--The American Petroleum Institute (API) number is a unique eleven digit number assigned to each wellbore. It is based on state, county, and a sequential well number. It is sometimes displayed as a hyphenated number (state-county-well number).

BW — Barrel of water, one barrel contains 42 gallons.

CBNG — Coalbed natural gas, also known as coalbed methane (CBM).

Economic limit — The minimum amount of gas production from a well required to provide enough cash flow to pay the operating cost and royalty expenses for that well.

EUR -- Estimated ultimate recovery of natural gas and/or crude oil for a specific well or group of wells.

gpm — Gallon per minute, a standard measurement of water production from wells.

MBW — Thousand barrels of water

MCFG — Thousand cubic feet of natural gas, MCF is a standard unit of measurement for natural gas usually at one atmosphere (14.7 psi) and 60^{o}F.

MMCFG — Million cubic feet of natural gas.

Nominal pumpage rate — As used in this report is the rate of water production from a well or group of wells assuming all the wells produced for every day during the month.

Spud — To begin drilling, or when the drill bit begins to drill below the earth's surface.

WOGCC — Wyoming Oil and Gas Conservation Commission, a state of Wyoming agency that regulates oil and gas production

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Appendix A

Estimates of future pumpage rates may be calculated by using the two equations listed below. Estimates are based on production history and decline rates. Such estimates may be problematic however. Figure A-1 shows pumpage rates for a two-township area in the Powder River Basin. In this area the coalbed gas potential has been fully developed. The area has been referred to as the Fairway area and Marquis-Lighthouse area.

Erratic pumpage rates often occur during early stages of coalbed gas development in a drainage basin. It is difficult to determine when and at what rate the pumpage will stabilize. Before rates stabilize at a more or less constant level, there is a decline period during which pumpage rates decrease in a more or less predictable way. Once this decline begins, rates can be predicted by the equations shown below. The historical rate q_i (initial pumpage rate, usually the last month for which there is reliable date) can be used to predict a future rate q, if the rate of decline is known. If a monthly pumpage rate is calculated, a decline curve can be constructed.

Exponential decline: $q = q_i e^{-at}$

Hyperbolic decline: $q = q_i (1 + b a_i t)^{-1/b}$

The two decline equations listed above are commonly used in the oil and gas industry. The variables are:

q_i-initial production rate,
q-the production rate you wish to determine at some time after q_i,
a-the decline rate for a specific time period (time periods must be consistent),
t-the time period for the decline rate a (for example 20%/year) and
b-a factor based on rock and fluid properties (generally the less permeable the reservoir rocks the higher the b value).

For a more complete discussion of decline curve analysis the reader is referred to Thompson and Wright (1985) or any good petroleum property evaluation text. Figures A-2 and A-3 show that the projected pumpage rates and resultant water production are relatively insensitive to the type of decline curve used. A convenient way of displaying data is on a semi log plot as shown in figures three and four. Exponential declines will form a straight line on semi log plots. In the examples shown, which used the same data as Figure 3, the difference between projections based on exponential and hyperbolic declines are shown. Although significant, the use of different decline equations is relatively minor compared to selecting the wrong starting point for the decline. In this illustration a two stage approach was used. A decline rate of 45 percent/year was used until the average pumpage rate reached two gallons/minute. Then the decline rate was changed to 10 percent/year. This two stage approach more closely approximates the actual average pumpage rates observed. During the time period shown in Figures two, three, and four the number of producing wells increased from 1 to 730 then declined to about 300. The maximum number of producing wells occurred in September 2001. Figure 2 shows the percent of wells drilled. The estimated total number of wells is based on well spacing as provided by the WOGCC. In the case of the two townships reviewed in this appendix, it was assumed that every spacing unit will be drilled. In some drainage basins estimated drilling will not cover the entire drainage basin.

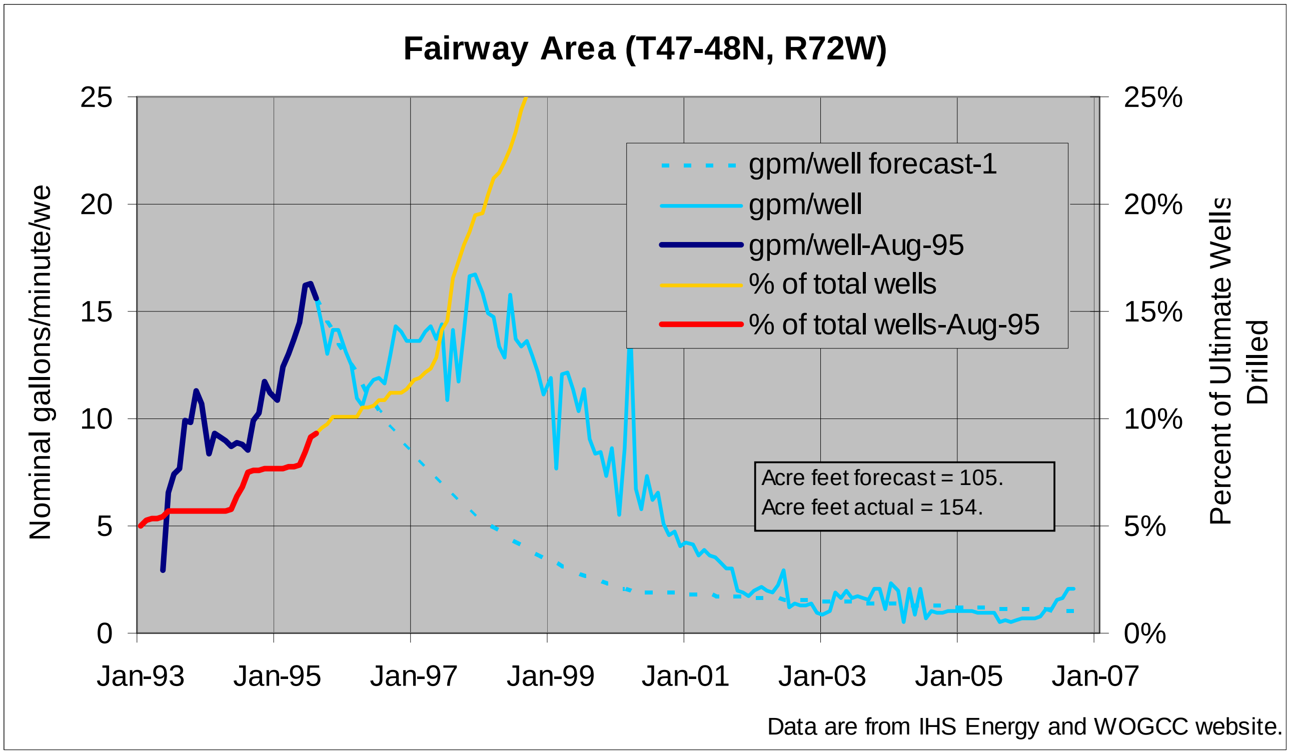

Figure A-1. Graph of the average pumpage rate in nominal gallons/minute for the Fairway area. An estimate of future rates is shown based on the assumption that the maximum rate was reached in August 1995. This assumption is in error. The resultant total per-well estimated water production through September 2006 would be only 68 percent of what actually was produced.

Exponential decline usually occurs in highly permeable strata such as the majority of Powder River Basin coals. The hyperbolic decline equation is used for less permeable rocks such as may occur in deeper horizons of the Powder River Basin and in other intermountain basins. The hyperbolic decline equation is of little use when calculating estimates for most Powder River Basin coals. When using this method to predict pumpage rates, it is important to keep units consistent. Production exhibiting exponential decline in a well will form a more or less straight line on a semi log graph. Production exhibiting hyperbolic decline will form a curved line on a semi log graph. When using the hyperbolic decline equation it is necessary to recalculate the decline rate a for each time period (day, month, year, etc.). The decline rate can be determined by the equation:

$$a = \ln(q_i/q)$$

where q_i and q are the initial and final rates over a time period.

Application of this method of estimating pumpage rates is almost always complicated by the difficult task of selecting a point on the pumpage rate graph where decline begins. If a decline is projected too soon the quantity of water withdrawn may be significantly underestimated. Examples from the Fairway area are shown below. In Figure A-2 the exponential decline formula was used to forecast the average pumpage rate. An annual decline rate of 45 percent was used until the pumpage rate was two gallons/minute then it was changed to 10 percent. Figure A-1 is a linear plot therefore the projected pumpage rate decline is a curved line. Figure A-1 shows how critical it is to calculate a projected decline rate only after the average pumpage rate has started to decline. In August 1995 only nine percent of the total wells had been drilled. By January 1998 twenty percent of the wells had been drilled and the projected pumpage rates are much more accurate. The reader is urged to use this method with great caution. The reader should also remember that during the time period shown in Figure A-2 the number of producing CBNG wells changed substantially (see Figure 3c).

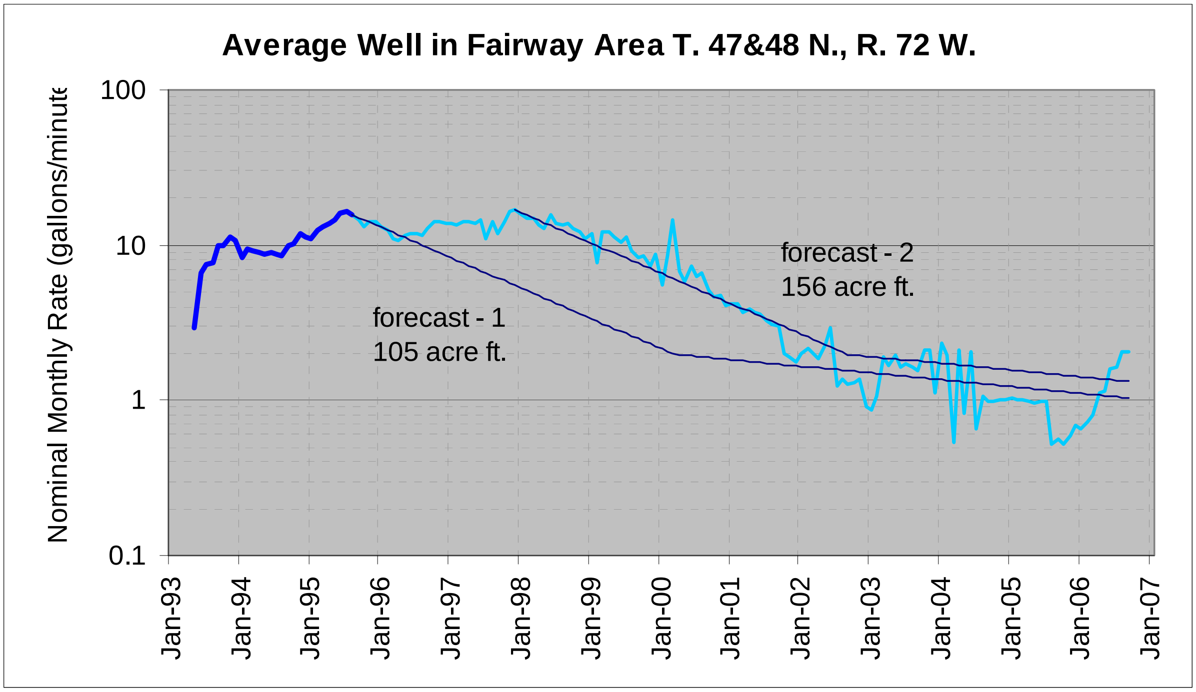

Figure A-2. This figure shows a two stage exponential decline to project future average pumpage rates. A two stage decline was used. An initial rate of 45 percent/year was used until the average pumpage rate reached two gallons/minute. Then the rate was changed to 10 percent/year. This two stage approach more closely approximates the actual average pumpage rates observed in the Fairway area. As pumpage rates decline to about one gallon/minute the decline rate may need to be reduced to zero.

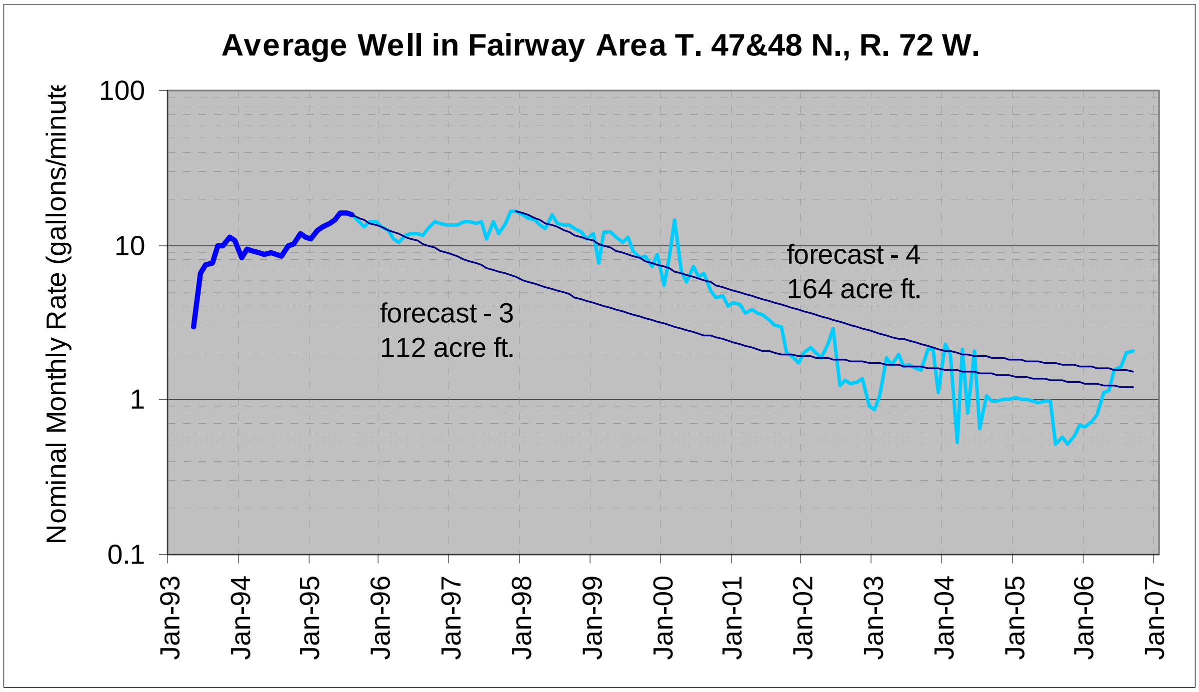

Figure A-3. This figure shows how the hyperbolic equation predicts future average pumpage rates. A two stage decline was used. An initial stage starts with a decline rate of 45 percent/year and a hyperbolic decline was used until the average pumpage rate reached two gallons/minute. Then the rate was changed to an exponential rate of 10 percent/year. This two stage approach more closely approximates the actual average pumpage rates observed in the Fairway area.