Update and Revision of Interim Drainage Report on Coalbed Methane Development and Drainage of Federal Land in the South Gillette Area, Campbell and Converse Counties, Wyoming T. 40-50 N., R 70-75 W.

February 12, 2001

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Summary

Coalbed methane (CBM) is released from coal when the hydrostatic pressure is reduced. This occurs when water is pumped from CBM wells. As pressure is reduced CBM gas begins flowing into the wellbore and is produced to the surface. Although about 40 percent of the mineral ownership in the producing CBM area in the Powder River Basin is federal, only 15 percent of current CBM production is from federal wells (see Figure 1).

Pressure data from water monitor wells and CBM wells indicate some pressure depletion has occurred over a 24 township area south of Gillette. The depleted area expanded about three to four miles westward during the past year. This expansion should be expected to continue during the next several years.

Substantial federal drainage is occurring in 13 townships in the South Gillette area. In two townships drainage is so severe that undrilled federal acreage may not support economic wells. In a three township area drainage caused estimated well recoveries to decrease by two-thirds, and this decrease will almost certainly become larger. Federal wells not drilled timely will recover much less gas than offsetting nonfederal wells. This report covers pressure drawdown in a 66 township area south of Gillette.

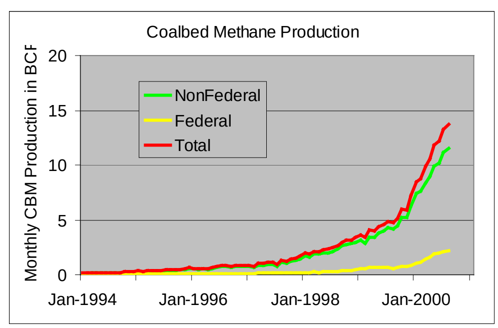

Figure 1 Nonfederal and federal CBM production from January 1994 to August 2000. Federal coalbed methane production averaged only 15 percent of total during January 2000-July 2000 even though about 40 percent of the mineral acreage is Federal. Graph data are from the Wyoming Oil and Gas Conservation Commission website.

Introduction

The average annual increase in CBM production from the Powder River Basin has been 66 percent since January 1994. In August 2000, 14 billion cubic feet (BCF) of CBM was produced in Wyoming, most of it from the 66 township area covered in this report. The comparison between federal and total CBM production is shown in Figure 1. The number of producing CBM wells shows a similar trend. Although 54 percent of the Powder River Basin and about 40 percent of the area currently developed for CBM is federal minerals, only 15 percent of the CBM production and 12 percent of the wells are federal. In August 2000 there were 3,390 producing and 1,953 shut-in coalbed methane wells. Through August 2000, 213 BCF of CBM had been produced from the Powder River Basin. This is less than one percent of the estimated coal gas reserves in the basin (Finley and Goolsby, 2000).

Pressure Decline and Methane Desorption

When hydrostatic pressure at the top of the coal is decreased by pumping water from coal seams, gas is released (desorbed) from the coal, migrates to the wellbore and is produced to the surface. Hydrostatic pressure and the rate of CBM production give an indication of whether or not drainage is occurring.

The gas adsorptive capacity has been measured for numerous coal samples throughout the Powder River Basin. Although most of these data are still confidential, Figure 2 was constructed based on averaged synthesized adsorptive capacities. Lines for one standard deviation above and below the average are also shown. The average synthesized isotherm indicates gas adsorptive capacity increases with depth following the relationship:

$$GC = -0.000059\, P^2 + 0.14\ 4\, P + 2.1$$

where GC = gas content in standard cubic feet/ton of coal (scf/ton), and P = reservoir pressure in pounds per square inch absolute (psia).

Water monitor wells in the South Gillette area indicate that most coals are undersaturated with CBM. Hydrostatic pressure at the top of the coal generally shows a decline of 10 to 40 percent before CBM begins to desorb.

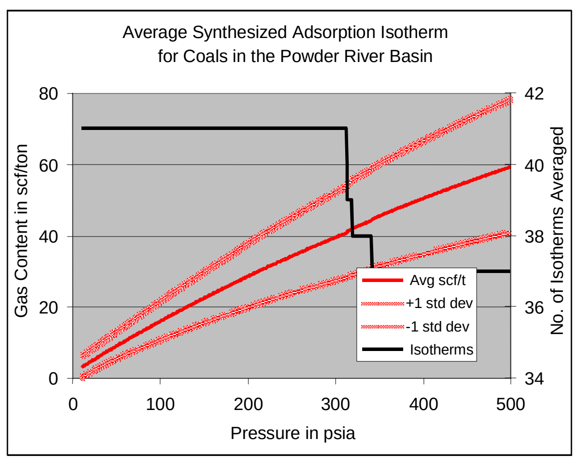

Figure 2 Average synthesized adsorption isotherm for 41 coal samples from the Powder River Basin, Wyoming. Lines for plus and minus one standard deviation are also shown. The isotherm is based on a compilation of data from public and private sources. Most of the specific data are confidential.

Explanation of Pressure Depletion Zones

Map 1 shows relative pressure depletion in the South Gillette area. This map is based on the best data available and shows general pressure depletion. In areas where pressure data were not available pressures declines were estimated by using a simulator program (Almasy, personal communication). Site specific pressures, and resulting gas contents, may be substantially different than mapped.

When estimating the amount of CBM in areas with depleted pressure it should be noted that when pressure is depleted the capacity of the coal to hold CBM is also depleted. If coal is highly undersaturated with CBM (for example desorption starts at 50 percent of original reservoir pressure), the gas content will be small even though the current hydrostatic pressure is above the initial desorption pressure. The pressure distribution in the South Gillette area was divided into five zones (see Map 1). Each zone is identified by color and is summarized below:

> Zone one (P_h=0.8P_{hi} to 0.9P_{hi},)--Green--probably contains little drainage from undrilled federal acreage.
>
> Zone two (P_h=0.6P_{hi} to 0.8P_{hi},)--Pink--contains some drainage from federal acreage but most of the CBM is still present. It is unlikely that more than one-third of the CBM has been drained from undrilled federal acreage. In most areas the amount of drainage is much less than one-third, and some areas have little or no drainage.
>
> Zone three (P_h=0.4P_{hi} to 0.6P_{hi},)--Gold--has experienced drainage throughout most of the area. In some parts of this zone CBM may be as much as half depleted from undrilled federal acreage.
>
> Zone four (P_h=0.2P_{hi} to 0.4P_{hi},)—White--most of the area probably contains less than half the original gas. Some parts of this zone may contain as much as three-fourths of the initial gas content; however, this would only be where coals were highly undersaturated with low original gas contents. In a few areas undrilled federal acreage may not support economic wells.
>
> Zone five (P_h=0.0P_{hi} to 0.2P_{hi},)--Blue--is badly drained. In much of the area undrilled federal acreage may not support economic wells.

In the above discussion of pressure depletion zones P_h is current hydrostatic pressure, and P_{hi} is original hydrostatic pressure at the top of the coal.

In areas where pressure has been badly depleted (such as zone five) gas will be left in place on undrilled federal acreage even though most of this gas could have been economically produced if wells had been drilled earlier when the gas content and hydrostatic pressure were higher. The amount of gas needed to justify drilling a well depends primarily on price. Recent gas prices have been relatively high. Assuming a gas price of $4.00/MCF and reasonable drilling, completion, and operating expenses, at least 40 MMCF would be necessary to drill and complete an economic CBM well. CBM in depleted areas where less than 40 MMCFG/well can be recovered, will remain uneconomic unless the gas price increases substantially, or costs decrease enough to justify development. Furthermore, producing wells will continue to deplete the gas in many of these undrilled areas.

Map 2 shows the pressure distribution from the previous drainage report (Crockett 2000). Most of the critical pressure measurements used in the previous report were taken about one year ago. The 40 percent and 80 percent of original pressure contours are shown on Map 2. The relative positions of the 40 and 80 percent contours give a good idea of how quickly pressure is being depleted. In most areas, the 40 and 80 percent contours moved approximately three to four miles westward between October 1999 and October 2000. It should not be assumed that this rate will continue or will be duplicated in other areas. The rate of change in hydrostatic pressure depends on many highly variable factors. However, it can be assumed that if the CBM play continues without unexpected interruption, these large pressure depletions will continue expanding westward for several years. Map 3 shows the specific data points used to generate the maps shown in this report. Map 4 shows the five pressure drawdown zones discussed above and the location of CBM wells as of June 2000. All the maps in this report show only relative pressure drawdown compared to original hydrostatic pressure. For a detailed discussion of pressure drawdown refer to Meyer 1999. Additional details about data and correlations used in this report are available in Appendix A.

Conclusions

Nonfederal CBM production continues to be about six to seven times more than federal CBM production. In order for federal CBM production to achieve parity with non-federal production, non-federal CBM production should be no more than about one and one-half times federal production in the developed area. Pressure depletion levels in the South Gillette area have moved about three to four miles west during the past year. Although many factors may affect the rate of pressure depletion, pressure depletion should be expected to continue moving westward during the next several years.

In most cases, drainage of CBM from undrilled federal acreage does not commence until hydrostatic pressure is less than 90 percent of original hydrostatic pressure. In areas where current hydrostatic pressure is less than 60 percent of original hydrostatic pressure, extensive CBM drainage may be occurring. In areas where current hydrostatic pressure is less than 20 percent of original hydrostatic pressure, drainage is so extensive that much of the undrilled federal acreage may not support economic wells. Although no attempt was made to quantify the amount of drainage from federal land in the South Gillette area, it can be concluded that CBM drainage represents a large transfer of wealth from the public to the private estate.

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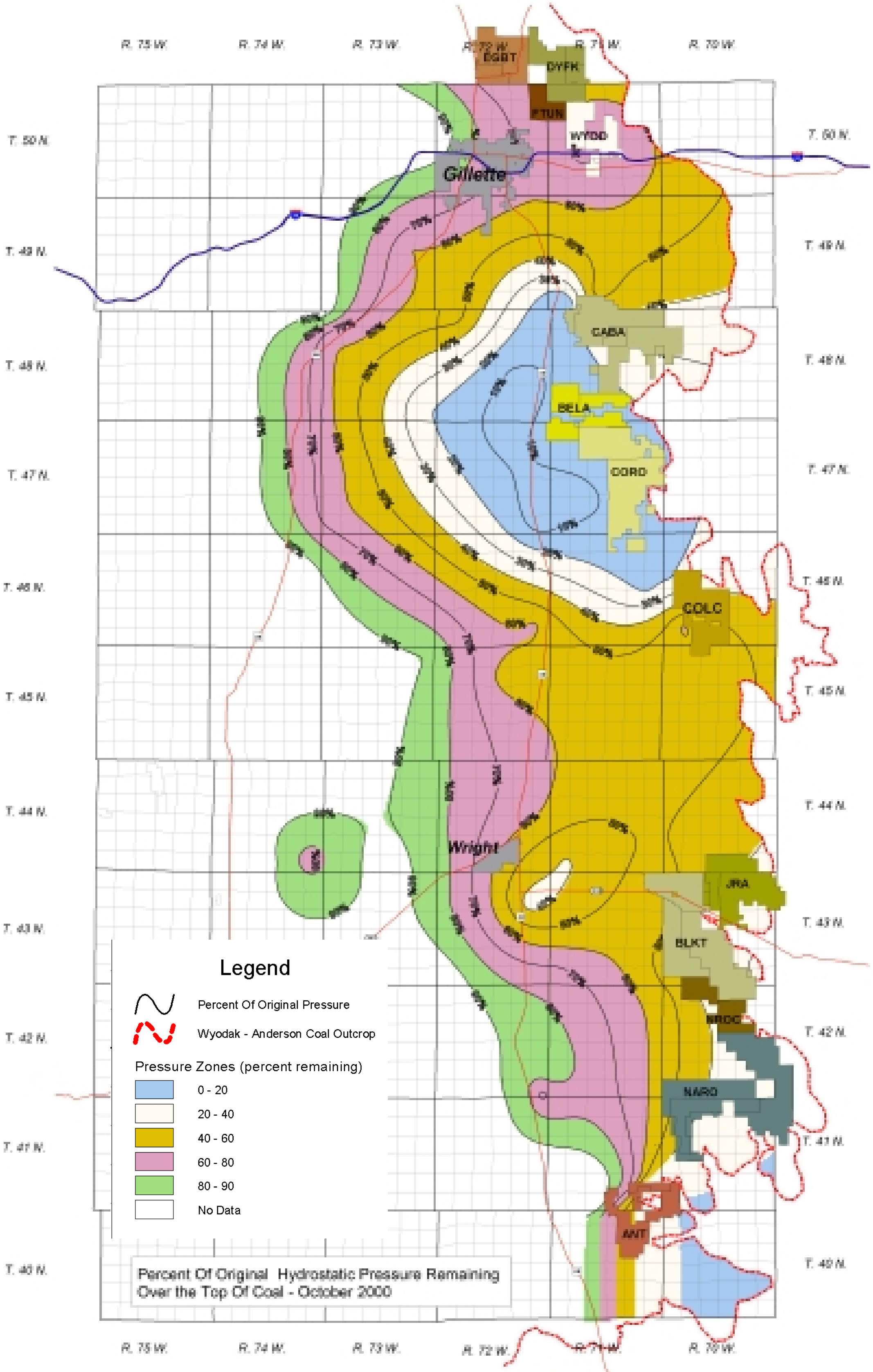
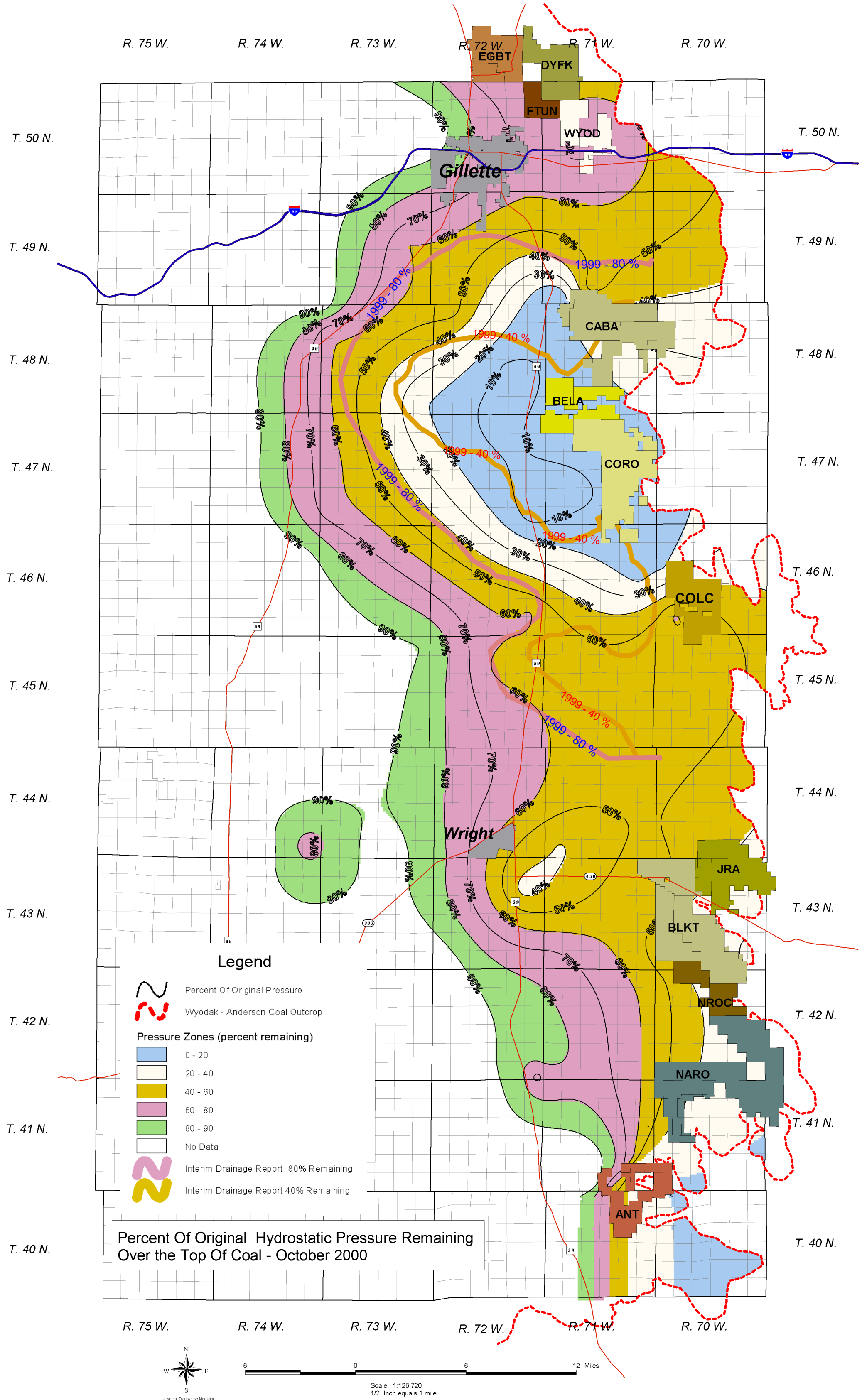
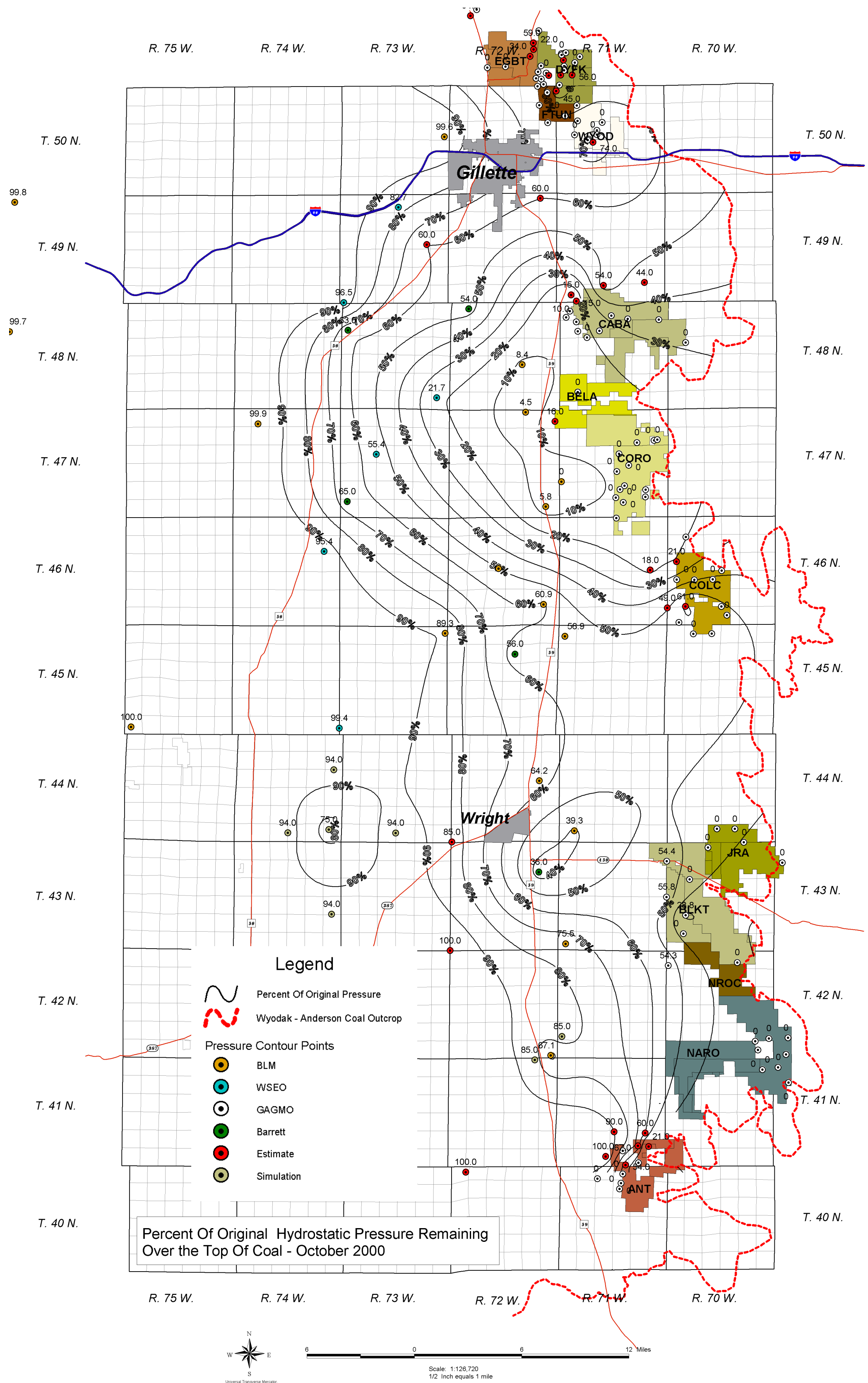


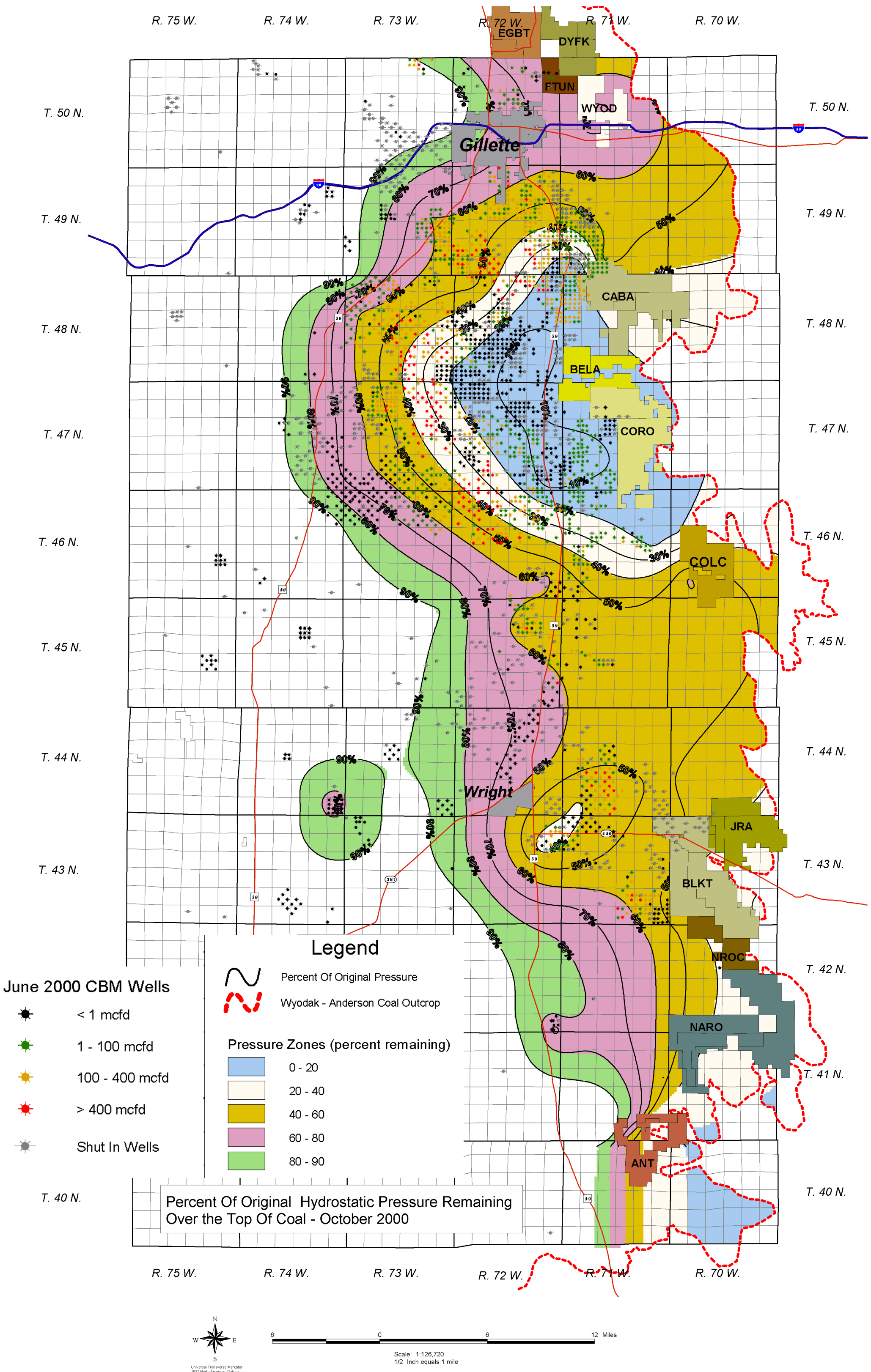
Map 1 This map shows percent of original hydrostatic pressure remaining in the South Gillette area in October 2000. Five pressure depletion zones are identified. Data are from BLM, Wyoming State Engineers Office (WSEO), Gillette Area Groundwater Monitoring Organization (GAGMO), and CBM operators. Additional Contour points were estimated from previous data or calculated by using a simulator. Map 3 identifies specific points.



Map2 This map shows percent of original hydrostatic pressure remaining in the South Gillette area as of October 2000. For comparison the 40 percent and 80 percent of original pressure lines from the February 2000 interim drainage report show how far pressure depletion has moved since October 1999.



Map 3 This map shows percent of original hydrostatic pressure remaining in South Gillette area in October 2000. The data points used to construct the contour lines are identified.



Map 4 This map shows percent of original hydrostatic pressure remaining in the South Gillette area in October 2000 and the location of producing gas wells as of June 2000. Well data are from WOGCC.

Appendix A

Data and Correlations

Data

Data from 122 wells completed in the Wyodak-Anderson coal were used in this analysis. Data sources included 92 wells operated by the Gillette Area Groundwater Monitoring Organization (GAGMO), six wells operated by the Wyoming State Engineers Office (WSEO), 19 wells operated by the Bureau of Land Management (BLM), and pressure observations in five coal bed methane (CBM) production wells provided by several CBM operators.

Water levels for each monitoring well were compiled for October 1980, 1997, 1998, 1999, and 2000. Many GAGMO wells did not have values available for the year 2000. Water levels for the year 2000 were estimated for 31 GAGMO wells based on previously measured declines, and trends in adjacent wells. Pressure data provided by CBM operators was also used to estimate 2000 water level data.

Methods

Initial pre-development (1980) water levels were used to calculate an initial formation pressure over the top of the coal at each well. Subsequent water levels were then used to calculate the pressure loss by year from the starting pressure. Pressure remaining over the top of the coal was calculated as a percent of the original pressure.

Pressure data was contoured using a commercial contouring package (Surfer) to develop a pressure-loss contour map for the area. Contours were generated directly from point to point without consideration to changes in geologic conditions.

Limitations

Water levels estimated for October 2000 in GAGMO wells are not as accurate as actual measurements. Estimated values were necessary because not all GAGMO members were able to provide 2000 data at this time. Pressure estimates near the outcrop are very sensitive to small changes in water level. Initial pressure over the top of coal near the outcrop is low, so even relatively small declines in water level can result in significant declines in the percent of original pressure remaining at any given point near the outcrop.

The density of monitoring wells away from the outcrop (range 72 to 75 west) is low. Measured changes in a single monitoring well can result in predicted pressure losses over relatively large areas due to the effects of contouring from relatively widely spaced data points. Also, pressure declines resulting from CBM wells located more than eight miles from a monitoring well may not be detected, resulting in under prediction of pressure loss in those areas.

Reservoir simulations conducted by the BLM Reservoir Management Group (RMG) were used to estimate pressure loss in areas where monitoring well data was not adequate to define conditions. These simulated points were input into the contouring routine to produce the final pressure maps. Accuracy of the resulting maps in these areas is dependent on the accuracy of the simulated points.

Professional judgement was used to estimate remaining pressures in several areas based on observed trends in monitoring wells, pressure data provided by CBM operators, and results of reservoir simulations conducted by RMG. These estimated points were required to prevent contouring anomalies resulting from widely spaced data points. In general, the estimates should be relatively accurate, but variations of several miles are possible.

Finally, local variations in geologic conditions can result in short-range variations in pressure loss which were not accounted for in this contouring exercise. Sufficient data were not available to adjust pressure loss based on localized changes in geologic structure. This analysis is intended to look at regional trends present in the Wyodak-Anderson coal zone, and may have significant limitations if applied to small scale, site specific conditions.

Correlations

Coalbed methane (CBM) is desorbed from coal when hydrostatic pressure on the coal is sufficiently reduced. Water monitoring wells in the South Gillette area have recorded water levels and casing pressure for several years. In the South Gillette area, the initial drop in hydrostatic pressure is not accompanied by immediate gas desorption. This indicates that coals in the South Gillette area are generally undersaturated with gas. Figure A1 shows data from a water monitor well in the South Gillette area. Note the substantial decrease in hydrostatic pressure before gas desorption started. Gas desorption is generally indicated by an abrupt increase in casing pressure.

Table 1 summarizes data from 21 water monitor wells. Nine of the wells indicate that CBM is desorbing. Initial desorption pressures (the pressue where desorption starts) vary from 40 to 92 percent of original hydrostatic pressure. The average desorption pressure is 73 percent of original hydrostatic. One well (Section 2, T. 47 N., R. 72 W.) started desorbing gas at 40 percent of original hydrostatic pressure, which was substantially less than the other wells. If this well is disregarded the average desorption pressure is 77 percent of original hydrostatic pressure. Two-thirds of the wells were desorbing CBM by the time the hydrostatic pressure had been

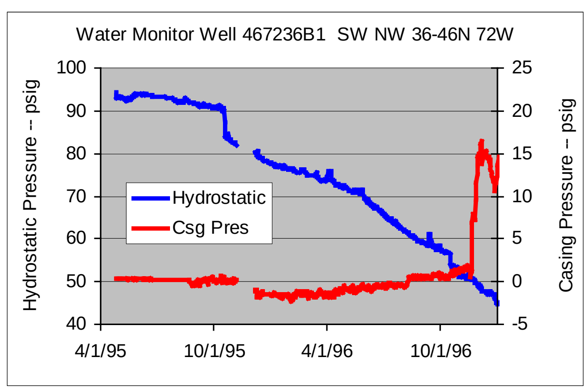


Figure A1 Data from BLM water monitor well. Note that hydrostatic pressure at the top of coal decreased substantially before desorption began.

Well Location	Depth of Top Coal-Ft	Top Coal P_{hi}-psig	Top Coal P_{di}-psig	P_{di}/P_{hi} %-psig	Remarks
SW SE 36 42N 72W	712	112			Not desorbing
NW SE 31 43N 71W	580	104	90	87%	Pd estimated from linear regression.
SE NE 31 44N 71W	664	147			Not desorbing
NE SE 14 44N 72W	716	194			Not desorbing
NE SW 6 45N 71W	328	91	84	92%	
SE NE 1 45N 73W	726	244			
NE SW 31 45N 75W	1,459	434			Not desorbing
NE SW 6 46N 71W	310	66	53	81%	
SW SE 16 46N 72W	750	176	152	86%	Max casing pres only 2.4psig, data end 6/98.
SW SW 25 46N 72W	420	161	122	76%	P_{di} may have been 99 psig.
SW NW 36 46N 72W	459	173			Data stopped 6-96, not desorbing
SW SW 19 47N 71W	334	39	29	76%	
NW NW 2 47N 72W	336	74	30	40%	
SW SW 7 47N 72W	830				Data not reliable-completion problem.
SW NW 36 47N 72W	492	109	65	60%	Top and base of coal from WOGCC.
SE SW 5 47N 74W	1,426	457			Not desorbing
SE NE 22 48N 72W	438	115	68	59%	
NE SW 12 48N 77W	1,435	522			Not desorbing
SE NE 1 49N 77W	1,320	412			Not desorbing
SW SE 13 50N 73W	647	93			Well was desorbing when completed
16 44N 73W	979	265			Average of 6 wells
36 44N 73W	1024	217			Average of 8 wells
Average				73%	

Table A1 Water monitor wells in the South of Gillette area. The wells are all completed in the Wyodak, Anderson, or Big George coals. Original and desorption pressures were determined based on the type of graph shown in Figure A1. The data are from BLM files, updated to November 2000. P_{di} = initial desorption pressure. P_{hi} = original hydrostatic pressure.

reduced to 75 percent of original hydrostatic pressure. Figure A2 shows the relationship between original hydrostatic pressure and initial desorption pressure at the top of the coal for the nine monitor wells that are desorbing gas. Note that there appears to be a general linear relationship of the form:

$$P_{di} = 0.86\ P_{hi} - 11$$

where P_{di} = initial desorption pressure in psia (pounds per square inch absolute) and P_{hi} = original hydrostatic pressure in psia. If the original hydrostatic pressure is known in an area, Figure A2 allows the initial desorption pressure to be estimated. Although Figure A2 indicates the relationship between hydrostatic pressure and initial desorption pressure in the south Gillette area, it may not be valid for other parts of the coalbed methane play area.

Original hydrostatic pressure is available from a variety of sources, the most common

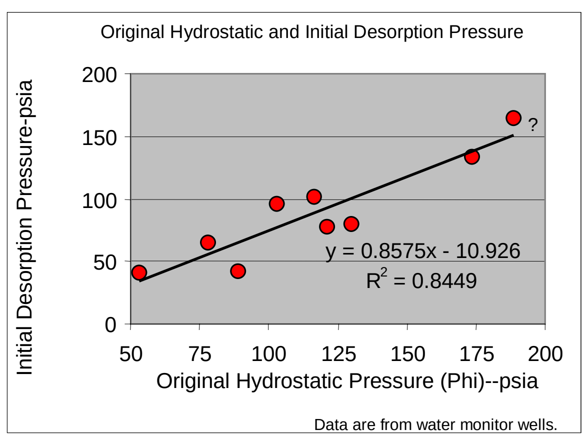


Figure A2 Original hydrostatic pressure and initial desorption pressure at the top of coal for nine water monitor wells in the south Gillette area. Data are from BLM files and are current to November 2000, see Table A1.

of which is CBM wells and water monitor wells. Before a well is placed on production, fluid levels are frequently measured. If these wells are far enough away from producing CBM wells, fluid level measurements probably are a good indication of original water levels in the area. The original hydrostatic pressure can then be calculated by using a pressure gradient of 0.433 psi per-foot of depth. Pressures calculated using this procedure should be accurate to within a few psi.

In order to estimate gas content from Figure 2, gauge pressure must be converted to absolute pressure. The following equation can be used to estimate absolute pressure for elevations less than 6200 feet:

$$\text{psia} \approx \text{psig} + 14.73 - (0.000496 * \text{Elevation in feet})$$

Original hydrostatic pressure can be estimated using Figure A3. Figure A3 is a graph of original hydrostatic pressure plotted against depth to the top of coal and shows a general linear correlation. After solving for P_{hi} the relationship in Figure A3 can be written as:

$$P_{hi} = 0.38\,D - 63$$

where D = depth in feet to top of coal. The correlation shown in Figure A3 is rather tenuous. Abrupt changes in topography will cause substantial changes in depth to coal within a relatively small geographic area. Therefore this correlation should be used to estimate original hydrostatic pressure only when no other pressure data are available. A correlation between elevation of the top of the coal and P_{hi} should have a better correlation than shown in Figure A3. However, this is not the case using the available data.

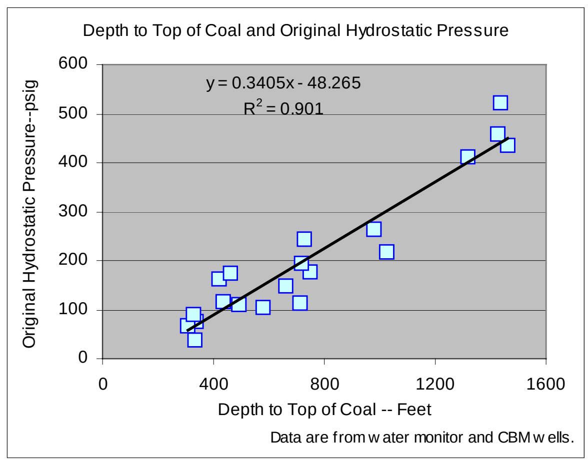


Figure A3. Depth to top of coal and original hydrostatic pressure. Data are from BLM files and CBM operators.

The relationship between original hydrostatic pressure and initial desorption pressure is critical. If initial desorption pressure is known then the isotherm in Figure 2 can be used to estimate the initial gas content of the coal.

Laboratory generated adsorptive capacity data were modeled by a second or third degree polynomial, then the equation for the polynomial was used to calculate (synthesize) gas adsorptive capacities for a series of pressures. The synthesized isotherms were only calculated for the pressure range of the laboratory measurements. Therefore, the number of isotherms decreases from 41 to 29 as pressure increases to 500 psia. The calculated adsorptive capacities for each pressure increment were averaged, and the average synthesized isotherm is shown in Figure 2. The isotherm and a brief summary can be down loaded from the BLM web site at www.wy.blm.gov/minerals/og/res.mgt/IsothermAncmnt.pdf. The website also references a file transfer protocol (ftp) site with the available public data.

Figures A4 a, b, and c allow estimates of gas content for declining pressures. Separate graphs are drawn for P_{hi} of 100, 200, and 400 psia. Each graph contains lines for P_{di} of 60, 80, and 100 percent of P_{hi}. An approximate depth is also given for each graph in Figure A4. However, this depth should be used only as a general guideline. Note that there is very little difference in the shape of the curves for various depths and original hydrostatic pressures. Figures A4 a, b, and c are based on the generalized synthesized isotherm shown in Figure 2, and the correlations shown in figures A2 and A3.

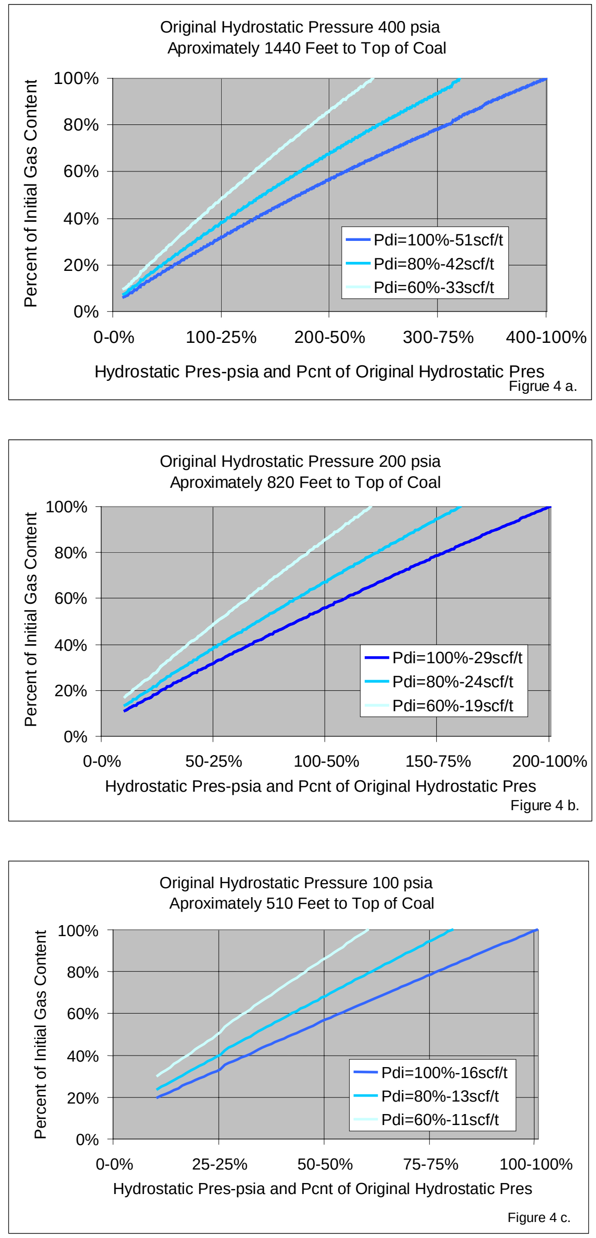


Figure A4 a, b, and c. Graphs showing hydrostatic pressure and relative amount of initial gas content for various depths (approximate) to top of coal. Gas contents are for the top of the coal and should not be used as an average for the entire coal seam. These graphs were derived from figures 2, A2, and A3.

Maps 1 through 4 can be used in conjunction with Figure A4 to estimate the relative amount of gas depleted due to pressure drawdown. In order to make this estimate, it is necessary to know the approximate original hydrostatic pressure or the depth. Once this is known, either Figure A4 a, b, or c can be selected. To estimate gas depletion enter the appropriate graph from the x-axis (abscissa) and move vertically to the desorption curve then read the percent of remaining gas off the y-axis (ordinate). If the appropriate desorption curve is not shown it may be necessary to interpolate between curves.

Figure A5 shows this process for an area where the coal is about 1000 feet deep, current hydrostatic pressure is 40 percent depleted, and where initial desorption began at 85 percent of original hydrostatic pressure. The procedure is relatively straight foreward. Start with the graph with a depth that is closest to 1000 feet, Figure A4b. Next, by interpolation locate a point on the x-axis that represents 60 percent of original hydrostatic pressure. Then move vertically to an interpolated location that would be on the 85 percent desorption line, about one-fourth of the distance from the 80 percent line to the 100 percent line. This is point B in Figure A5. Next move straight across to the y-axis and read the results. Under this scenario, 74 percent of initial gas in place is remaining after hydrostatic pressure has been reduced by 40 percent from original hydrostatic pressure.

The gas content in the coal can be estimated by using Figure 2. Once saturation has been achieved (gas has started desorbing from the coal) the gas content can be estimated by going directly to Figure 2. If the coal is undersaturated then the initial desorption pressure, or saturation pressure, must be estimated first. Then the gas content may be estimated directly from Figure 2.

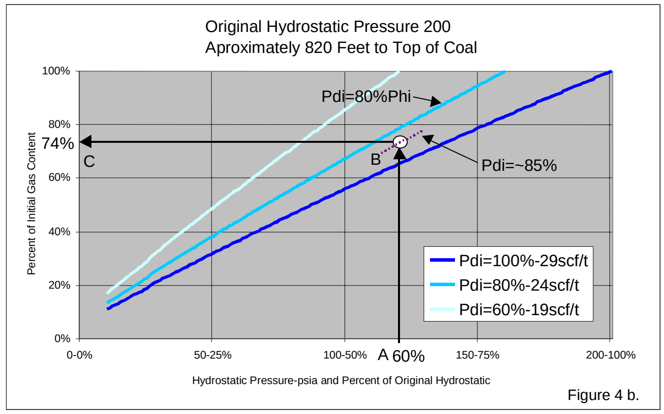


Figure A5. This graph shows an example of how to estimate the approximate percent of CBM depletion for a pressure drop of 40 percent from original hydrostatic pressure if methane desorption starts at 85 percent of original hydrostatic pressure.

Figure A6 shows the decline in estimated ultimate recoveries (EUR) of CBM based on normalized data from wells drilled in sequential years in part of the South Gillette area (T. 47-48 N., R. 71-72 W.). EURs decreased from 0.44 BCFG/well to 0.14 BCFG/well. This decline will almost certainly continue as pressure continues to decline. There is no obvious correlation between depth, coal thickness, or number of wells drilled/year, and the EUR. Figure A6 reflects the substantial decline in recoverable CBM as hydrostatic pressure declined. Map 1 indicates that in October 2000 hydrostatic pressure was less than 20 percent of original hydrostatic pressure in most of the area where data for Figure A6 were collected. A graph showing estimated well life shows the same trend as Figure A6. It shows a decline from twelve years down to three years over the same time interval.

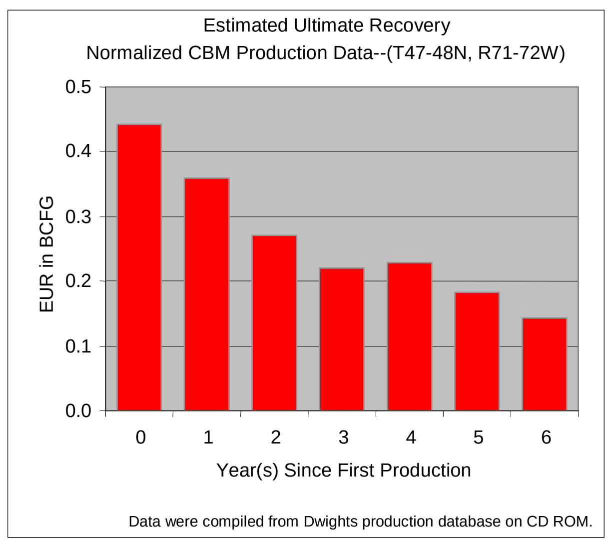


Figure A6 Graph of decline in estimated ultimate recoveries for CBM wells in part of the South Gillette area. Year 0 represents 1993. Data were compiled from Dwights production database.

Figures 2, A2, and A3 indicate that there is probably not enough pressure for economic CBM until the top of the coal is about 200 feet or more below the surface. Figure A4 suggests there is probably substantial drainage occurring by the time pressure depletion reaches 60 percent of original hydrostatic pressure. If these two estimates are accurate, there are 13 townships in the South Gillette area where substantial drainage from undrilled federal acreage is probable. In at least two townships pressure is so depleted (less than 20 percent of original hydrostatic pressure) undrilled federal locations may not support economic wells.

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