ENHANCEMENT OF THE APPALACHIAN BASIN DEVONIAN SHALE RESOURCE BASE IN THE GRI HYDROCARBON MODEL

GRI Contract No. 5095-890-3478

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December 1997

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1. INTRODUCTION

In the GRI baseline projection, increased gas production from shales in the Appalachian Basin plays an important role in increased lower-48 gas production. In the 1995 edition of the GRI Baseline Projection, annual shale production grows from an estimated 218 billion cubic feet (Bcf) in 1993 to almost 400 Bcf in the year 2000, and almost 800 Bcf in 2010. This is more than 10 per cent of the increased lower-48 production projected to occur during that period.

The current description of the Appalachian Basin shale resource base in the GRI Hydrocarbon Model was developed about eight years ago. Since this estimate was made, there have been modest technology advances in the Appalachian Basin. Advances in technology have been significant in the Michigan Basin over the same period. Although near-term shale production in the Appalachian Basin seems reasonably consistent with current industry results, after the 1990's, the resource description predicts a rapid growth in shale production in the Appalachian Basin such that by 2010, production is projected to be almost four times that for 1993.

Given the age of the resource description in the Appalachian Basin, it is desirable to revisit it in light of current industry results, activity, and expectation, and to evaluate whether the resource description is consistent with industry results, and whether the post-1990's optimism seems warranted.

The objective of this study was to construct a database of production data for Devonian shale gas wells completed in a large area within southwestern West Virginia, to compute recoveries, and to compare these recoveries to those estimated by GRI in the 1980's for both a base case, and an advanced case assuming technology improvements. We also set out to determine historical and geographic patterns in production and recovery in wells completed since 1980, and to attempt to account for temporal and spatial trends.

2. THE DATABASE AND METHODOLOGY

Data on well locations, completions, pay zones, and annual and monthly production were extracted from the West Virginia Geological and Economic Survey's (WVGES) oil and gas database. The data were extracted using the play definitions of the two Devonian Shale plays described in *The Atlas of Major Appalachian Gas Plays* (Roen and Walker, 1996). Data for missing years in reported production were reconstructed in the following manner. Whenever a single year of missing production was encountered, reported production for the preceding and succeeding years was examined. If production for the year prior to and the year after the missing year was present, a simple average was entered for the missing year. In any other situation, no attempt was made to reconstruct the value, no value was entered in the yearly production total, and the well was not counted as producing for that year.

Statistical analyses and plotting of graphs were carried out with the help of commercial spreadsheet programs on personal computers. Maps were created with a commercial mapping and contouring program on a Unix workstation.

Ultimate gas recovery was estimated for each well by multiplying production in the last year of available production by 14.24, and adding this figure to known cumulative production.

For each cell within the study area, average annual production was calculated for all wells with available data. The ratio of decline was calculated for available years, and used to extrapolate decline curves out to thirty years. Annual figures were also used to compute average cumulative production out to thirty years. Graphs of annual production versus cumulative production represent a type of decline curve, and were drawn in lieu of conventional decline curves. Both the decline curves and graphs of cumulative production with year were examined for geographic trends.

3. RESULTS

3.1 Recent Drilling and Production Trends

As the data for this project have been derived from the WVGES Oil and Gas Database, a short summary of the condition of the data available for this project is necessary. The annual drilling activity in West Virginia has been steadily declining since the early eighties (Figure 1). The period 1981-1985 was the time of greatest activity, with both total wells and shale wells at their highest numbers. Much of this activity can be attributed to the effects of the Natural Gas Policy Act (NGPA) of 1978. As a result, the average annual gas price tripled from 1979 ($1.05) to 1980 ($3.00), resulting the in the peak years of the early 80s. By the mid-80s purchasers ceased paying the higher prices for gas (including shale gas) under the NGPA, resulting in the steady decline of drilling activity in West Virginia. However, the tax credit for Devonian shale gas continued for wells drilled between January 1, 1980 to December 31, 1992. This supported exploration and production of shale gas in the late 1980's when the price of gas declined.

Figure 2 shows a primary problem with the WVGES data. WVGES data are developed from information provided to the state by operators. As a result, some years in the mid-80s are under-reported and any analysis of the data must take this into account. The low reporting numbers for 1985, 1986, and 1987 can be attributed to a change in the State regulatory agency's reporting procedures. Only in 1988 did the number of wells with production reports reach pre-1985 levels. To account for this discrepancy in the later analysis, an estimation of missing production was made as described in the section on methodology.

Filling those gaps that could be “bridged” allowed construction of reasonable annual production charts (Figure 3). Comparison with Figure 2 indicates that highest production totals coincide with years that have the greatest number of reported wells. It also indicates that total production of natural gas in West Virginia has slowly, steadily increased coincident with an increase in the number of wells reporting production. At the same time, production from the shales has also increased at a steady rate, also corresponding to a steady increase in the number of wells reporting production from the shales (Figure 2).

A graph of monthly production (Figure 4) shows a serious problem associated with poor reporting for 1985. Although production per well is highest in 1985 (Figure 5), total monthly production taken directly from the database (Figure 4) indicates a large decline in production for the year. There may have been a bias in data collection or data entry in 1985; the better wells may be included in the data set. Also, in the course of our Devonian shale studies for GRI, we did made an effort to target certain operators for production data collected for 1985.

As these charts all show a steady increase in production, actual performance of wells can be judged by the average yearly production (Figure 5). It can be seen that production per well in West Virginia has been steadily declining since monthly highs over 500 Mcf in 1985, to the rather steady 350-400 Mcf/month that the late 80s and early 90s have experienced. Combining the shale-wells average to the state average shows that, in general, shale wells have performed above the average for the state. Average production from shale wells has declined from highs of 900-1000 Mcf/month in the early 1980's to current production of about 600 Mcf/month. This average of 600 Mcf/month has remained steady since 1988. Although the number of wells reporting increases, the production per well does not; this suggests that newer wells are not getting better.

3.2 Location of Devonian Shale Wells and Devonian Shale Plays

Figure 6 is a map of the West Virginia portion of the Appalachian Basin showing the location of GRI cells 1 - 32 and the position of all wells assigned to Gas Atlas Plays Dbg (Devonian black/gray shales and siltstones) and Dbs (Devonian black shales). Examination of the figure shows that wells for the two plays form two fairly distinct north-south trending bands separated by a relatively non-productive area. Only cells 11, 15, 20, and 25 contain wells from both plays. The lack of a more gradual transition between the two plays is probably a result of the absence of structural "modifications" (ie., fracturing of the black and gray shales and siltstones) necessary to facilitate production of gas and the reduced thickness of black, organic-rich shales in this region.

3.3 Gas Production by Vintage

Gas production for shale wells was analyzed by “vintage”. The vintage of a well is based upon the reported completion date for that well. The WVGES Oil and Gas database maintains production data from 1979 to the present. Data on shale production are not plentiful before 1981, therefore, any shale production prior to 1981 is grouped into a single vintage. The remaining vintages used for this analysis were 1982-1985, 1986-1989, and 1990-1993. Production beyond 1993 was not available. Finally, for each vintage, the production was separated into the black and gray Devonian Shales (Dbg), representing the siltier shale play found to the east of the primary shale area and the Devonian Black Shales (Dbs), representing the original shale play. Graphs of total production and average production were generated for each play (Figures 7 - 10).

Figure 7 indicates that production in the black and gray shale play has been increasing, although data for the most recent vintage are incomplete. On the other hand, production in the typical black shale (Figure 8) has been declining, and the most recent vintage of black shale wells (while also incomplete) suggests that this trend will also continue. Graphs of production per well offer similar conclusions. Production per well in the black and gray shales has steadily increased (Figure 9), with the newest wells offering greatest production. Production per well in the black shale play (Figure 10) shows a general decline, but, as with wells in the black and gray shales, the most recent wells have the greatest production. Production per well in the black shale play was maintained at 6-8 MMcf annually until the early 90's. The newest wells show an increase to 11-12 MMcf.

Two explanations can be given for these data: 1) newer shale wells are being drilled “smarter” (i.e. only the best wells are being drilled, or newer wells are stimulated more effectively, using new techniques) and 2) new shale production is being co-mingled with up-section production (i.e. targets in the Berea, Big Injun, Weir, and Big Lime). It is most likely that the increased production per well is being achieved through a combination of the two.

3.4 Gas Recovery

Recovery by Year of Completion

Results were aggregated by year of completion and play, where play Dbg is the black and gray shales and siltstones, and Dbs is the black shales to the west.

Average gas recovery has increased over time (Figure 11), especially in play Dbg compared with Dbs (Figures 12 and 13). This increase could be the result of greater selectivity that came with more geologic knowledge and changing economics. With time, drillers knew which areas resulted in poor productivity; after the mid-1980's, it was important to avoid these areas because gas prices could not justify drilling low-volume wells. As drillers have become more familiar with reservoirs in the area of play Dbg, there may have been an increase in the effectiveness of well completion, but we have no data to test this suggestion.

Average recoveries in Dbs (Figure 13) changed little over time, reflecting the maturity of this play. The very best and very worst areas for drilling in this play have long been known and are either drilled up in the former case, or avoided in the latter.

This conclusion is supported by the decrease in the range of recoveries experienced for play Dbg (Figure 12). Many wells completed in the early 1980's showed relatively low recoveries. Although the upper range of recoveries has remained steady over the period of years under consideration, much of the increase in average recovery has resulted from a decrease in the number of wells with relatively low recovery. After 1985, the sub-population of low-recovery wells is very small relative to the rest of the distribution.

Dbs (Figure 13) also experienced a change in the distribution of recoveries beginning with wells drilled in 1985. Because this region has long been drilled for shale gas, much more is known of the geology and the population of low-recovery wells in the early 1980's is not as large a proportion of the wells drilled as was the case for play Dbg. This results in the nearly flat curve of average recoveries in Figure 13.

There is a strong relationship between maximum production and recovery. This is true for the database of all data available (Figure 14), and for individual plays (Figures 15 and 16). The plays do not differ significantly in the relationship between these two variables.

To further analyze changes in well recovery since 1980, the percent of reserves was calculated for all wells with recovery at or below median recovery (50^{th} percentile). This statistic was computed for all wells completed in each of the 13 years 1981-1993. The same procedure was repeated for wells falling within the 51^{st} - 80^{th} percentile, and 81^{st} - 100^{th} percentile for each year. Results were graphed for the complete database (Figure 17), and for each of the two plays (Figures 18 and 19).

The trend since 1980 for all wells and in each of the two plays was an increase in the percent of reserves contributed by the below-median wells. This trend lasted until about 1988. This is consistent with the observation that the lower range of recoveries was truncated as companies drilled more selectively, or completed wells more successfully. This trend was accompanied by a decrease in the percent of reserves contributed by the best 20 per cent of wells as the distribution of recoveries became more symmetric (Figure 17).

Since 1988, the percent of reserves accounted for by the low-recovery wells has decreased, while the percent of reserves by the best wells has increased. The range of recoveries has increased since 1988, although average and median recovery have held steady or increased for most years.

In general, these results hold true for both plays.

Recovery and Interval Completed

We allocated wells between two groups based on whether they were completed exclusively in the Huron or stratigraphic equivalents, or completed in some other interval, possibly including the Huron. We call these two groups of wells “Huron” and “Other”. The “Other” group included wells completed in non-Huron Devonian strata and wells multiply completed in Huron and non-Huron strata; it should be noted that the number of wells completed in the first group is too small for statistical analysis. The Lower Huron Member of the Ohio Shale (Huron) was the main target of drillers throughout the southwestern part of West Virginia. In addition to graphs of recovery by play and interval completed, we created graphs that show trends through time.
Distributions of recoveries show a lot of overlap; comparison of the two distributions (Huron and Other) was best accomplished with graphs of cumulative percent (Figure 20). Wells completed in the Huron Member averaged much less (89 MMcf) in recovery than those completed in the Other category (138 Mmcf). Wells completed in the Huron (Figure 21) were less successful than those completed in the Other group. This is particularly true in play Dbg, where the lithologic contrast between Huron and other formations disappears to the east. In addition, many wells in play Dbg produce from multiple formations.

The preponderance of data are from wells completed in non-Huron Devonian shales in play Dbg, and therefore the overall trend in recovery tends to follow this curve through time (Figure 22), which is one of increasing recovery.

The curve for Huron wells is approximately flat, or declining in recent years (Figure 22), especially in play Dbs (Figs. 23 and 24). This could reflect the fact that initial gas production from the Huron interval in this play goes back many decades, and any improvements in completion method have not reversed a decline in recovery.

GRI versus WVGES Recoveries

Average well recovery was computed for each of the ten cells in the historic area for which sufficient data were available. Because we had found that recovery was related to the date of completion, we included only those wells completed in the 1990's. These wells presumably represent the current state of the art in well completion technology.

Results were compared with data provided by Thomas Woods of GRI. In the original study performed for GRI, the base case assumed an 88% success rate, and fracture length of 50 feet, and the advanced case assumed a 95% success rate and fracture length of 400 feet. We compared recoveries estimated from well data with the GRI figures for both the base case and the advanced technology case. Average well recovery and total recovery were computed for each cell.

On Figures 25-28, the diagonal, dotted line divides the graph into two areas: 1) below the line, recovery originating from GRI exceeds that calculated by WVGES; 2) above the line, the WVGES value exceeds the GRI value. Data are listed in Tables 3 and 4.

For the base case, neither average recovery (Figure 25) nor total recovery (Figure 26) as calculated by the WVGES shows a relationship with that provided to GRI. Thus, cells predicted to have the highest predicted or total recoveries did not necessarily yield the highest values estimated from actual production.

However, Both GRI and WVGES obtained similar overall average recovery whether by well, or by cell.

Cells predominantly or entirely representing play Dbs have failed to meet the GRI estimates for recovery per well and per cell, whereas 4 out of 6 cells in play Dbg exceed the GRI estimates. These four cells--numbers 21, 25, 26, and 30--lie in the southeastern part of the shale trend, an area where wells are generally completed in multiple intervals that include Mississippian reservoirs. Thus, for a large majority of wells, the only data available for analysis represent commingled production from both Devonian and non-Devonian reservoirs.

Equivalent graphs for the advanced case (Figures 27 and 28) show many of the same results: play

Dbg estimates of recovery exceed those computed for GRI previously in 4 out of 6 cells. The difference between the base case and the advanced case is that the overall mean values for per well recovery and total recovery by cell are higher for the GRI data.

We conclude that: 1) observed well performance more closely fits the base case as defined in the earlier report to GRI than the advanced case; 2) that there are real differences in expected recovery between the two plays; and 3) the two plays differ in the model for recovery that should be used. The difference in recovery model could depend on both the nature of the Devonian reservoir i.e. play Dbg vs. Dbs, and also in the nature of the other reservoirs in the study area, and frequency of completion in multiple reservoirs.

3.5 Gas Production Decline Curves and Cumulative Production

Decline curves (Figure 29) appear to belong to two types: nine curves show very slow decline, and four curves rapid decline in the first five years, starting from relatively high initial production levels. The latter four curves represent cells in the southern-most extent of play Dbg (cells 21, 25, 26, and 30) where shale gas is almost always commingled with gas produced from shallower reservoirs. Decline curves in the northern part of play Dbg (cells 12 and 16) are similar in value to those in play Dbs. Cells largely representing play Dbs can be further divided between the westernmost ones (cells 11, 14, 18, 19), and a band intermediate between plays Dbg and Dbs in both geographic location and decline.

Cumulative production curves (Figure 14) show basically the same trends as the decline curves.

4. SUMMARY

1) Wells for the two plays (Dbs and Dbg) form two fairly distinct north-south trending bands separated by a relatively non-productive area. Lack of a gradual transition between the two plays is the result of the absence of natural fractures in the black and gray shales and siltstones necessary to provide porosity and permeability, and the reduced thickness of black organic-rich shales.

2) Total production of gas from the Devonian shales declined during the period of study (1982-1993) because of a decrease in the number of wells drilled. However, production and estimated ultimate recovery per well increased, particularly in Play Dbg (gray and black shales and siltstones), either because better prospects are being drilled, or completions are more effective.

3) The percentage of reserves contributed by below-median wells increased between 1981 and 1988, then decreased. Again, selectivity in siting new wells and better completion practices could have caused these changes.

4) Wells completed in the Huron Shale were less successful than those completed in

intervals in addition to the Huron. This is particularly true in play Dbg, where the lithologic contrast between the Huron Shale and other formations disappears to the east, and where many completions are made in Mississippian reservoirs.

5) Average recovery per well was more comparable to expectations of the GRI base case model (50 ft fracture lengths) than the advanced case (400 ft fracture length).

6) Wells in play Dbg gave higher recoveries than wells in play Dbs, probably the result of the fact that data for many wells in play Dbg include production from shallower, Mississippian reservoirs.

7) Decline curves for wells in play Dbs and the northern part of play Dbg show very slow decline starting from relatively low production in the first year. Wells in the southern-most part of play Dbg display rapid decline in the first five years, starting from relatively high initial production levels. Shale gas is almost always commingled with gas produced from shallower reservoirs in this area.

5. REFERENCES CITED

Roen, John B. and Walker, Brian J. (editors), 1996, The Atlas of Major Appalachian Gas Plays, West Virginia Geological and Economic Survey Publication, V-25, Morgantown, WV, 201 p.

APPENDIX A. RECOVERIES FOR BASE AND ADVANCED CASES

The following tables list for each cell, average recoveries per well (MMcf) and total recovery (Bcf), as calculated for GRI (see Appendix B) and as calculated by the West Virginia Geological and Economic Survey (WVGES)**.**

BASE CASE

	GRI DATA			WVGES DATA	
	Recovery	Wells	Cell	Recovery	Cell
Cell	Per Well (MMcf)	Per Cell	Recovery (Bcf)	Per Well (MMcf)	Recovery (Bcf)
12	211.9	4287	908.4	104.7	449.1
15	305.8	4126	1261.7	139.0	573.7
16	503.8	4232	2132.1	294.4	1246.1
19	314.6	1203	378.5	259.8	312.5
20	326.9	3075	1005.2	153.8	472.8
21	250.6	3716	931.2	558.8	2076.5
24	469.1	2290	1074.2	352.8	808.0
25	250.7	3431	860.2	463.0	1588.7
26	188.1	2952	555.3	287.1	847.6
30	240.6	2112	508.1	712.7	1505.2

ADVANCED CASE

	GRI DATA			WVGES DATA	
	Recovery	Wells	Cell	Recovery	Cell
Cell	Per Well (MMcf)	Per Cell	Recovery (Bcf)	Per Well (MMcf)	Recovery (Bcf)
12	352.8	4628	1632.8	104.7	484.8
15	484	4454	2155.7	139.0	619.3
16	631.9	4569	2887.2	294.4	1345.3
19	433.4	1299	563.0	259.8	337.4
20	487.9	3320	1619.8	153.8	510.5
21	341.9	4012	1371.7	558.8	2241.9
24	728.7	2472	1801.3	352.8	872.2
25	418.9	3704	1551.6	463.0	1715.1
26	265.9	3186	847.2	287.1	914.8
30	355.3	2280	810.1	712.7	1625.0

APPENDIX B. GRI-SUPPLIED FORECASTS OF RECOVERY AND OTHER DATA BY CELL

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BASE CASE - HISTORIC AREA

	R	PROD. CZO	DEPTH (ft)	FI (ft)	NET DRILLABLE AREA (Sq.Mi.)	DRILL SUCCESS RATE	ADJUSTED NET DRILLABLE AREA (Sq.Mi.)	WELL SPACING (Ac.)	WELLS PER QUAD	GAS IN-PLACE PER WELL (MMcf)	QUADRANT GAS IN-PLACE (Bcf)	CUM. GAS IN-PLACE (Tcf)	TECH. RECOV. PER WELL (MMcf)	QUADRANT TECH. RECOV. (Bcf)	CUM. TECH. RECOV. (Tcf)	ECON. RECOV. PER WELL (MMcf)	QUADRANT ECON. RECOV. (Bcf)	CUM. ECON. RECOV. (Tcf)	GAS PRICE (1987 $ /Mcf)	BTU CONV. FACTOR (MMBTU /Mcf)	GAS PRICE (1987 $ /MMBTU)
14	28	32 H	3000	50	459.3	88.0%	404.14	80	3,233	790.0	2,902.4	2.90	495.3	1,601.3	1.60	495.3	1,601.3	1.60	1.33	1125	1.18
13	28	28 H	2300	50	493.5	88.0%	434.24	80	3,474	701.8	2,770.9	5.67	376.3	1,307.2	2.91	376.3	1,307.2	2.91	1.46	1100	1.33
23	20	28 H	3100	50	379.3	88.0%	333.74	80	2,670	1,271.9	3,858.9	9.53	525.5	1,403.1	4.31	525.5	1,403.1	4.31	1.62	1150	1.41
28	16	28 H	4900	50	617.8	88.0%	543.66	80	4,349	1,474.2	7,285.5	16.82	589.7	2,564.7	6.88	589.7	2,564.7	6.88	1.70	1150	1.48
24	20	32 H	3741	50	325.3	88.0%	286.26	80	2,290	1,223.2	3,182.8	20.00	469.1	1,074.3	7.95	469.1	1,074.3	7.95	1.76	1150	1.53
19	24	32 H	3253	50	170.9	88.0%	150.39	80	1,203	608.6	832.0	20.83	314.6	378.5	8.33	308.1	370.7	8.32	1.89	1150	1.64
16	28	40 H	4750	50	601.2	88.0%	529.01	80	4,232	2,015.2	9,691.1	30.52	503.8	2,132.1	10.46	503.8	2,132.1	10.45	2.10	1150	1.83
22	20	24 H	2400	50	530.8	88.0%	467.06	80	3,736	769.5	3,287.3	33.79	307.8	1,150.1	11.61	[illegible]	1,150.1	11.60	2.11	1150	1.83
18	24	28 H	3000	50	510.7	88.0%	449.37	80	3,595	1,118.5	4,569.1	38.36	404.7	1,454.9	13.07	[illegible]	1,454.9	13.06	2.19	1150	1.90
27	16	24 H	2950	50	769.4	88.0%	677.07	80	5,417	951.8	5,858.4	44.22	358.2	1,940.1	15.01	[illegible]	1,940.1	15.00	2.28	1150	1.98
29	16	32 H	5100	50	508.6	88.0%	447.52	80	3,580	1,129.8	4,596.0	48.81	470.2	1,683.4	16.69	[illegible]	1,683.4	16.68	2.36	1150	2.05
20	24	36 H	4036	50	436.9	88.0%	384.43	80	3,075	1,638.5	5,726.6	54.54	326.9	1,005.5	17.70	[illegible]	1,005.5	17.69	2.89	1150	2.51
21	24	40 H	4778	50	527.9	88.0%	464.55	80	3,716	1,253.0	5,291.4	59.83	250.6	931.3	18.63	244.3	907.9	18.60	3.14	1150	2.73
17	24	24 H	1000	50	534.3	88.0%	470.18	80	3,761	761.1	3,252.9	63.09	169.5	637.5	19.26	169.5	637.5	19.23	3.14	1150	2.73
1	40	28 H	830	50	356.7	88.0%	313.90	80	2,511	900.6	2,570.3	65.66	173.9	436.8	19.70	173.9	436.8	19.67	3.10	1100	2.82
15	28	36 H	3791	50	586.1	88.0%	515.77	80	4,126	1,440.9	6,756.6	72.41	305.8	1,261.6	20.96	305.8	1,261.6	20.93	3.39	1150	2.95
10	32	32 H	2243	50	421.7	88.0%	371.06	80	2,968	514.2	1,734.6	74.15	203.6	604.3	21.57	203.6	604.3	21.54	3.26	1100	2.96
25	20	36 H	5235	50	487.4	88.0%	428.87	80	3,431	992.6	3,870.3	78.02	250.7	860.1	22.43	246.7	846.4	22.38	3.47	1150	3.02
5	36	28 H	820	50	346.6	88.0%	304.96	80	2,440	688.8	1,909.4	79.93	138.0	336.6	22.76	138.0	336.6	22.72	3.79	1100	3.45
8	36	40 H	2410	50	482.1	88.0%	424.25	80	3,394	662.0	2,553.3	82.48	132.4	449.5	23.21	123.4	418.7	23.14	4.28	1100	3.89
11	32	36 H	3468	50	499.3	88.0%	439.34	80	3,515	1,067.9	4,265.4	86.75	208.7	733.6	23.95	208.7	733.6	23.87	4.48	1125	3.98
6	36	32 H	2070	50	451.2	88.0%	397.01	80	3,176	471.3	1,701.1	88.45	147.7	469.1	24.42	147.7	469.1	24.34	4.44	1100	4.04
2	40	32 H	1670	50	438.8	88.0%	386.10	80	3,089	644.7	2,262.9	90.71	122.5	378.5	24.79	116.9	361.0	24.70	4.47	1100	4.06
9	32	28 H	716	50	405.0	88.0%	356.40	80	2,851	503.5	1,631.3	92.34	118.0	336.4	25.13	118.0	336.6	25.04	4.54	1100	4.13
12	32	40 H	4440	50	609.0	88.0%	535.88	80	4,287	733.3	3,572.8	95.91	211.9	908.4	26.04	211.9	908.3	25.95	4.77	1150	4.15
7	36	36 H	3100	50	470.0	88.0%	413.56	80	3,308	686.4	2,560.9	98.49	161.5	534.2	26.57	161.5	534.2	26.48	5.06	1100	4.60
26	20	40 H	5636	50	419.3	88.0%	368.94	80	2,952	950.0	3,186.3	101.68	188.1	555.1	27.13	188.0	554.9	27.03	5.76	1150	5.01
3	40	36 H	2770	50	414.3	88.0%	364.55	80	2,916	704.7	2,335.4	104.02	133.9	390.4	27.52	133.9	390.4	27.43	5.82	1100	5.29
30	16	36 H	5920	50	300.0	88.0%	264.00	80	2,112	1,584.5	3,802.8	107.82	240.6	508.1	28.03	240.6	508.1	27.93	6.22	1150	5.41
4	40	40 H	3490	50	420.5	88.0%	370.00	80	2,960	730.0	2,455.7	110.27	136.2	403.0	28.43	136.2	403.1	28.34	6.93	1100	6.30
					13,973.0		12,298.2		98,370		110,274.2			28,429.6			28,336.4				

29-Nov
04:29 PM

ADVANCED CASE - HISTORIC AREA

	R	PROD. CZO	DEPTH (ft)	FI (ft)	NET DRILLABLE AREA (Sq.Mi.)	DRILL SUCCESS RATE	ADJUSTED NET DRILLABLE AREA (Sq.Mi.)	WELL SPACING (Ac.)	WELLS PER QUAD	GAS IN-PLACE PER WELL (MMcf)	QUADRANT GAS IN-PLACE (Bcf)	CUM. GAS IN-PLACE (Tcf)	TECH. RECOV. PER WELL (MMcf)	QUADRANT TECH. RECOV. (Bcf)	CUM. TECH. RECOV. (Tcf)	ECON. RECOV. PER WELL (MMcf)	QUADRANT ECON. RECOV. (Bcf)	CUM. ECON. RECOV. (Tcf)	GAS PRICE (1987 $ /Mcf)	BTU CONV. FACTOR (MMBTU /Mcf)	GAS PRICE (1987 $ /MMBTU)
23	20	28 C,H	3320	400	379.25	95.0%	[illegible]	80	2,882	1,431.3	4,342.6	4.34	862.4	2,485.7	2.49	862.4	2,485.7	2.49	1.12	1150	0.97
28	16	28 C,H	5160	400	617.80	95.0%	[illegible]	80	4,695	1,654.2	8,175.1	12.52	881.7	4,139.8	6.63	881.7	4,139.6	6.63	1.21	1150	1.05
14	28	32 C,H	3330	400	459.25	95.0%	436.29	80	3,490	896.7	3,294.5	15.81	656.9	2,292.8	8.92	652.9	2,278.9	8.90	1.20	1125	1.07
27	16	24 C,H	3170	400	769.40	95.0%	730.93	80	5,847	1,311.2	8,070.7	23.88	695.1	4,064.6	12.98	695.1	4,064.8	12.97	1.32	1150	1.15
18	24	28 C,H	3310	400	510.65	95.0%	485.12	80	3,881	1,234.8	5,044.3	28.93	731.6	2,839.3	15.82	731.6	2,839.4	15.81	1.45	1150	1.26
24	20	32 C,H	5600	400	325.30	95.0%	[illegible]	80	2,472	1,408.3	3,664.3	32.59	728.7	1,801.6	17.62	728.7	1,801.7	17.61	1.69	1150	1.47
19	24	32 C,H	3675	400	170.90	95.0%	162.36	80	1,299	746.2	1,020.1	33.61	433.4	562.9	18.19	427.3	555.0	18.17	1.69	1150	1.47
13	28	28 C,H	2505	400	493.45	95.0%	468.78	80	3,750	745.3	2,942.4	36.55	438.1	1,643.0	19.83	431.1	1,616.7	19.78	1.66	1100	1.51
29	16	32 C,H	6250	400	508.55	95.0%	483.12	80	3,865	1,349.0	5,487.7	42.04	744.6	2,877.9	22.71	744.6	2,877.9	22.66	1.90	1150	1.65
22	20	24 C,H	2675	400	530.75	95.0%	504.21	80	4,034	878.9	3,732.0	45.77	431.0	1,738.5	24.45	431.0	1,738.4	24.40	1.96	1150	1.70
16	28	40 H	6275	400	601.15	95.0%	571.09	80	4,569	2,015.2	9,691.1	55.46	631.9	2,887.0	27.33	631.9	2,887.2	27.29	2.55	1150	2.22
10	32	32 H,R	2510	400	421.65	95.0%	400.57	80	3,205	552.6	1,864.0	57.33	312.3	1,000.9	28.33	312.3	1,000.9	28.29	2.51	1100	2.28
20	24	36 H,R	5123	400	436.85	95.0%	415.01	80	3,320	1,943.1	6,791.0	64.12	487.9	1,619.9	29.95	487.9	1,619.9	29.91	2.64	1150	2.30
25	20	36 H,R	5883	400	487.35	95.0%	[illegible]	80	3,704	1,223.7	4,771.1	68.89	418.9	1,551.5	31.51	418.9	1,551.4	31.46	2.85	1150	2.48
15	28	36 C,H	4620	400	586.10	95.0%	556.80	80	4,454	1,665.8	7,811.1	76.70	484.0	2,155.9	33.66	484.0	2,155.9	33.61	2.89	1150	2.51
7	36	36 C,H	3600	400	469.95	95.0%	446.45	80	3,572	1,067.3	3,975.4	80.68	415.0	1,482.2	35.14	415.0	1,482.1	35.10	2.82	1100	2.56
11	32	36 H,R	4125	400	499.25	95.0%	474.29	80	3,794	1,293.9	5,167.7	85.84	416.2	1,579.2	36.72	416.2	1,579.2	36.67	2.97	1125	2.64
1	40	28 H	830	400	356.70	95.0%	338.87	80	2,711	900.6	2,570.3	88.42	195.0	528.5	37.25	195.0	528.6	37.20	3.23	1100	2.94
17	24	24 C,H	1000	400	534.30	95.0%	507.59	80	4,061	791.1	3,381.2	91.80	207.5	842.6	38.09	207.5	842.7	38.05	3.49	1150	3.03
6	36	32 H	2070	400	451.15	95.0%	428.59	80	3,429	471.3	1,701.1	93.50	188.1	644.9	38.74	186.5	639.6	38.69	3.51	1100	3.19
3	40	36 H,R	3030	400	414.26	95.0%	393.55	80	3,148	759.4	2,516.7	96.01	234.3	737.8	39.48	234.3	737.8	39.42	3.81	1100	3.46
12	32	40 H,R	6238	400	608.95	95.0%	578.50	80	4,628	1,194.5	5,819.4	101.83	352.8	1,632.8	41.11	352.8	1,632.8	41.06	4.01	1150	3.49
4	40	40 C,H	4100	400	420.45	95.0%	399.43	80	3,195	1,292.6	4,348.2	106.18	349.7	1,117.5	42.23	349.7	1,117.5	42.17	3.89	1100	3.54
5	36	28 H	820	400	346.55	95.0%	329.22	80	2,634	688.8	1,909.4	108.09	153.6	404.5	42.63	153.6	404.5	42.58	3.97	1100	3.61
2	40	32 H	1670	400	438.75	95.0%	416.81	80	3,335	644.7	2,262.9	110.35	141.0	470.2	43.10	132.1	440.6	43.02	4.01	1100	3.65
30	16	36 H,R	6060	400	300.00	95.0%	285.00	80	2,280	1,786.1	4,286.7	114.64	355.3	810.1	43.91	355.3	810.1	43.83	4.31	1150	3.75
21	24	40 H,R	5988	400	527.90	95.0%	501.51	80	4,012	1,680.2	7,095.5	121.74	341.9	1,371.7	45.28	341.9	1,371.8	45.20	4.63	1150	4.03
9	32	28 H	716	400	405.00	95.0%	[illegible]	80	3,078	503.5	1,631.3	123.37	140.2	431.5	45.71	140.2	431.5	45.63	4.85	1100	4.41
8	36	40 H,R	4670	400	482.10	95.0%	[illegible]	80	3,664	782.6	3,018.6	126.39	304.2	1,114.6	46.83	250.7	918.6	46.55	4.96	1100	4.51
26	20	40 H,M	6813	400	419.25	95.0%	[illegible]	80	3,186	1,091.1	3,859.6	130.05	265.9	847.2	47.68	265.9	847.1	47.40	6.61	1150	5.75
					13,973.0		13,274.3		106,194		130,046			47,676			47,397.7				

APPENDIX C. DELIVERABILITY MARKERS

Using production data for Gas Atlas Plays Dbg and Dbs, and the specifications for calculation from GRI (Tom Woods, 1995, written communication), tables of productivity markers were constructed for each individual play and for both combined. The format of each table followed that given as an example in the same communication. Each table lists annual values for each of thirteen markers requested. In at least one instance, the procedure specified to calculate the marker, ie., UTIL % PROD COMPL, was determined to be incorrect (in this instance, the formulation as specified would not yield a percent) and was modified based on comparison to formulation of other similar markers.

Examination of each table and comparison to that supplied with the communication indicates that the calculated values of all markers for both Gas Atlas Plays and for the combined data set are comparable to the data supplied by GRI. However, a number of our markers, eg. CAPACITY AVG MAX1,2; CAPACITY DECLINE; and COINCIDENT MAX PROD, show an increase with time whereas the GRI values show a general decrease. The values of all of our UTIL % markers are considerably more variable than those shown in the GRI spreadsheet; our values do, however, appear to be stabilizing with time. Perhaps more interestingly, examination of the typical MONTH OF MAXimum production for our data indicates a significant number of maxima occurring in either late spring (March and April) or mid-summer (June and July), in addition to the December and January maxima observed in the GRI data. Finally, the UTIL % PROD COMP values for Play Dbg average approximately 15% of the year and for Play Dbs, approximately 7% of the year. This is in comparison to a fairly consistent 10% value for the GRI data.

ESTIMATED GAS WELL PRODUCTIVE CAPACITY (BCF) FOR GAS ATLAS PLAY Dbg

CATEGORY	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Annual Prod	28.94	23.39	446.08	1232.33	4455.42	6431.93	6185.07	12016.16	11461.28	12507.53	11413.00	13030.32	12144.99	13536.43	14378.59
# Prod Compl	1.00	1.00	105.00	252.00	769.00	989.00	1079.00	1566.00	1652.00	1835.00	1891.00	2011.00	2151.00	2250.00	2115.00
Capacity Max1	6.20	2.79	115.98	312.84	1173.69	1404.73	1189.24	2074.36	1651.75	1703.42	1558.11	1821.86	1631.00	1907.37	2028.08
Capacity Avg Max1,2	4.68	2.60	82.67	218.77	815.33	1035.14	865.50	1566.59	1240.72	1277.60	1168.51	1351.41	1302.17	1432.43	1529.77
Capacity Decline	6.20	5.27	116.54	346.88	1242.97	1909.02	1795.88	2361.73	2124.96	2009.38	1854.88	2057.55	1913.23	2146.30	2315.19
# Compl-Months	11.00	12.00	785.00	1703.00	5459.00	8947.00	10055.00	14579.00	17003.00	19538.00	19668.00	21292.00	22274.00	23567.00	23196.00
Util% Max1	38.90	69.90	32.10	32.80	31.60	38.20	43.30	48.30	57.80	61.20	61.00	59.60	62.10	59.10	59.10
Util% Avg Max1,2	51.50	75.10	45.00	46.90	45.50	51.80	59.60	63.90	77.00	81.60	81.40	80.40	77.70	78.70	78.30
Util% Decline	38.90	37.00	31.90	29.60	29.90	28.10	28.70	42.40	44.90	51.90	51.30	52.80	52.90	52.60	51.80
Util% Prod Compl	91.70	100.00	62.30	56.30	59.20	75.40	77.70	77.60	85.80	88.70	86.70	88.20	86.30	87.30	91.40
Coincident Max Prod	6.20	2.79	57.45	158.27	563.09	611.66	576.19	1127.47	1068.29	1137.48	993.39	1234.72	1099.62	1229.35	1537.78
Month of Max	6.00	3.00	10.00	12.00	11.00	7.00	10.00	10.00	1.00	1.00	4.00	1.00	3.00	12.00	10.00
Util% Coinc Max	38.90	69.90	64.70	64.90	65.90	87.60	89.50	88.80	89.40	91.60	95.70	87.90	92.00	91.80	77.90

ESTIMATED GAS WELL PRODUCTIVE CAPACITY (BCF) FOR GAS ATLAS PLAY Dbs

CATEGORY	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Annual Prod	0.00	26.16	1114.89	2619.48	4185.53	5967.53	5399.15	6342.81	6616.84	6929.74	7347.24	7290.53	6997.57	8792.73	8814.37
# Prod Compl	0.00	6.00	138.00	330.00	560.00	641.00	588.00	792.00	872.00	957.00	1017.00	1057.00	1108.00	1220.00	1223.00
Capacity Max1	0.00	15.14	212.31	485.38	812.08	1008.19	746.27	861.86	911.10	852.12	861.25	888.76	919.72	1130.88	1158.85
Capacity Avg Max1,2	0.00	8.53	141.96	374.29	633.25	746.42	570.97	655.59	692.05	713.19	727.77	762.74	772.12	914.89	936.11
Capacity Decline	0.00	15.14	212.45	528.70	892.89	1222.70	995.70	947.13	979.39	980.15	949.84	955.40	985.36	1205.78	1294.14
# Compl-Months	0.00	23.00	1053.00	2652.00	4634.00	6139.00	6500.00	8487.00	9472.00	10557.00	11584.00	12066.00	11914.00	13899.00	14065.00
Util% Max1	-99.90	14.40	43.80	45.00	43.00	49.30	60.30	61.30	60.50	67.80	71.10	68.40	63.40	64.80	63.40
Util% Avg Max1,2	-99.90	25.50	65.40	58.30	55.10	66.60	78.80	80.60	79.70	81.00	84.10	79.70	75.50	80.10	78.50
Util% Decline	-99.90	14.40	43.70	41.30	39.10	40.70	45.20	55.80	56.30	58.90	64.50	63.60	59.20	60.80	56.80
Util% Prod Compl	-99.90	31.90	63.60	67.00	69.00	79.80	92.10	89.30	90.50	91.90	94.90	95.10	89.60	94.90	95.80
Coincident Max Prod	0.00	14.52	148.38	260.07	521.38	611.29	491.37	605.45	689.99	634.62	654.32	648.76	631.14	765.03	899.67
Month of Max	0.00	12.00	12.00	12.00	12.00	12.00	12.00	1.00	4.00	12.00	4.00	9.00	2.00	2.00	10.00
Util% Coinc Max	-99.90	15.00	62.60	83.90	66.90	81.40	91.60	87.30	79.90	91.00	93.60	93.60	92.40	95.80	81.60

ESTIMATED GAS WELL PRODUCTIVE CAPACITY (BCF) FOR ALL DEVONIAN WELLS

CATEGORY	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Annual Prod	28.94	49.55	1560.97	3851.81	8640.95	12399.46	11584.23	18358.97	18078.13	19437.27	18760.24	20320.85	19142.56	22329.15	23192.96
# Prod Compl	1.00	7.00	243.00	582.00	1329.00	1630.00	1667.00	2358.00	2524.00	2792.00	2908.00	3068.00	3259.00	3470.00	3338.00
Capacity Max1	6.20	17.93	328.29	798.22	1985.77	2412.92	1935.52	2936.22	2562.84	2555.55	2419.36	2710.62	2550.71	3038.25	3186.93
Capacity Avg Max1,2	4.68	11.13	224.63	593.06	1448.58	1781.56	1436.48	2222.18	1932.76	1990.79	1896.28	2114.15	2074.29	2347.33	2465.88
Capacity Decline	6.20	20.41	328.99	875.58	2135.86	3131.72	2791.58	3308.86	3104.35	2989.53	2804.71	3012.95	2898.59	3352.07	3609.33
# Compl-Months	11.00	35.00	1838.00	4355.00	10093.00	15086.00	16555.00	23066.00	26475.00	30095.00	31252.00	33358.00	34188.00	37466.00	37261.00
Util% Max1	38.90	23.00	39.60	40.20	36.30	42.80	49.90	52.10	58.80	63.40	64.60	62.50	62.50	61.20	60.60
Util% Avg Max1,2	51.50	37.10	57.90	54.10	49.70	58.00	67.20	68.80	77.90	81.40	82.40	80.10	76.90	79.30	78.40
Util% Decline	38.90	20.20	39.50	36.70	33.70	33.00	34.60	46.20	48.50	54.20	55.70	56.20	55.00	55.50	53.50
Util% Prod Compl	91.70	41.70	63.00	62.40	63.30	77.10	82.80	81.50	87.40	89.80	89.60	90.60	87.40	90.00	93.00
Coincident Max Prod	6.20	15.52	197.29	418.34	1041.33	1125.03	1053.11	1694.33	1664.99	1763.76	1647.71	1845.43	1700.29	1959.72	2437.45
Month of Max	6.00	12.00	12.00	12.00	12.00	7.00	12.00	12.00	4.00	1.00	4.00	1.00	3.00	12.00	10.00
Util% Coinc Max	38.90	26.60	65.90	76.70	69.10	91.80	91.70	90.30	90.50	91.80	94.90	91.80	93.80	95.00	79.30

APPENDIX D: GRI SPECIFICATION OF DELIVERABILITY MARKERS

The following pages list the deliverability markers with definitions supplied by GRI (Tom Woods, 1995, written communication.)

GRI

TO: Lee Avery (West Virginia Geological Survey)

FROM: Tom Woods (GRI)

DATE: 29 November 1995

SUBJECT: Deliverability Markers for the Lower-48

Attached to this memo are some tables on 1994 lower-48 gas reserves and the lower-48 deliverability markers that I told you about at the meeting in Morgantown. Please note that I use the term markers, not measures. Any absolute measure of deliverability without a total understanding of well capacity, gathering capacity, and gathering line backpressure is not very meaningful. I am sorry to be so tardy in sending the data to you.

The tables run from 1984 to 1994, but the 1994 data are only partial and should not be used. The years of good data run from 1974 through 1993. The data are labelled **Conventional** (actually all non-coalbed methane gas wells), **Coalbed Methane**, and **Total**. Each table has the following data:

Annual Production: The production is in billion cubic feet (Bcf).

 # Prod Compl: This is the number of wells completions producing during the year.

Capacity Max1: This capacity marker is the sum of the maximum monthly production for each producing completion during the year, regardless of the month in which it occurred. I call this marker the **Noncoincident Peak**. Production is in Bcf.

Capacity Avg Max1,2: This capacity marker is the average of the two highest monthly production rates for each producing completion during the year, regardless of the months in which they occurred. I do not really use this marker yet. Production is in Bcf.

Capacity Decline: This capacity marker is the maximum monthly production for a completion during the year if it began production in that year. If the completion produced during the previous year, its maximum production is the larger of 85 percent of the previous year's production or the current year's maximum. I call this marker **Throttled-back Noncoincident Peak.** These data only are good from 1971 through 1993 because we had no monthly production data for 1969. Production is in Bcf.

 # Compl-Months: This is the sum of the total months of actual production for each completion active during the year divided by **# Prod Compl** times 12.

Util % Max1: This is the average monthly production (**Annual Production** divided by 12) divided by **Capacity Max1** times 100.

Util % Avg Max1,2: This is the average monthly production (**Annual Production** divided by 12) divided by **Capacity Avg Max1,2** times 100.

Util % Decline: This is the average monthly production (**Annual Production** divided by 12) divided by **Capacity Decline** times 100.

Util % Prod Compl: This is the **# Compl-Months** divided by **# Prod Compl** times 12.

Coincident Max Prod: This is the peak monthly production for the year, usually December or January. I call this marker **Coincident Peak**.

Month of Max: This is the month of maximum production numbered 1 through 12 (January to December). **Util %-Coin Max:** This is the average monthly production (**Annual Production** divided by 12) divided by **Coincident Max Prod** times 100.

Overall, the tables show that the deliverability markers are well in excess of the average monthly or peak monthly production. The **Util% prod. compl.** indicates that gas wells are shut in on average about 10 percent of the year. In some regions the shut-in measures are much larger. While the markers indicate that takes are increasing, the takes are still well short of wellhead capacity, although not necessarily gathering capacity.

Attachments

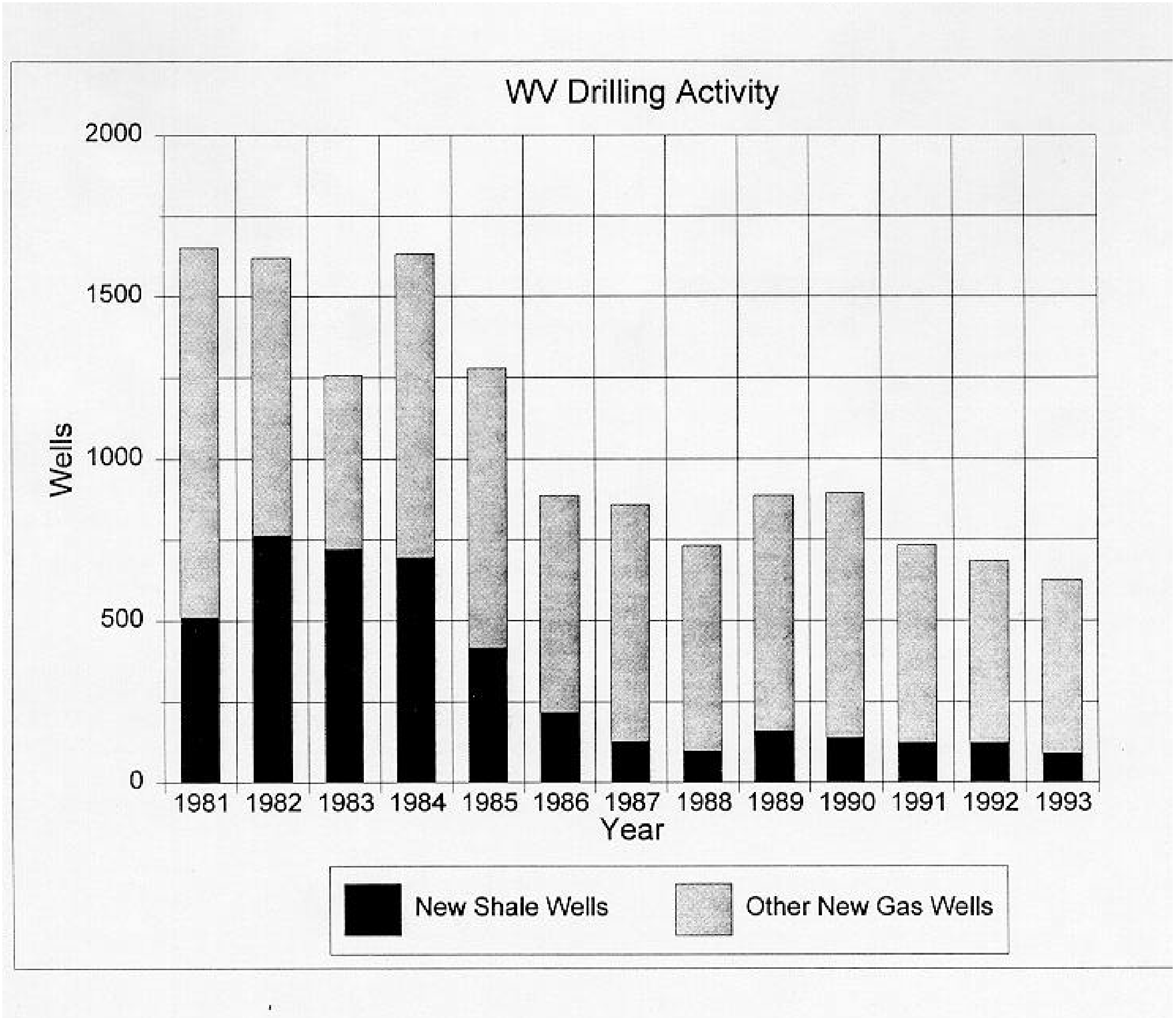

FIGURE 1. West Virginia drilling activity. Drilling activity is shown as total number of new gas wells and the number of new Devonian shale gas wells completed annually for the years 1981-1993.

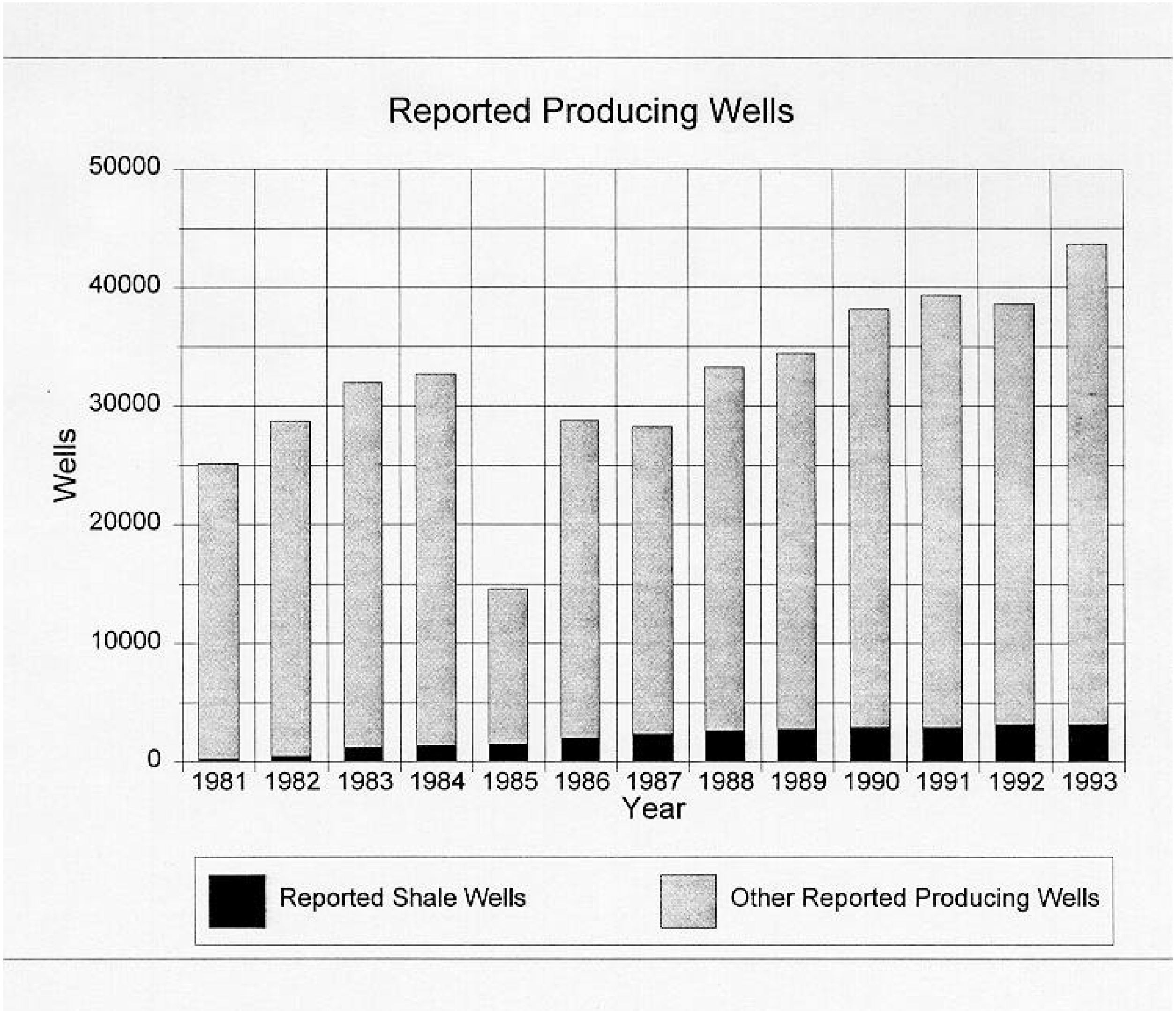

FIGURE 2. Total number of reported producing gas wells in West Virginia, and the number of reported West Virginia Devonian shale gas wells, for the years 1981 to 1993.

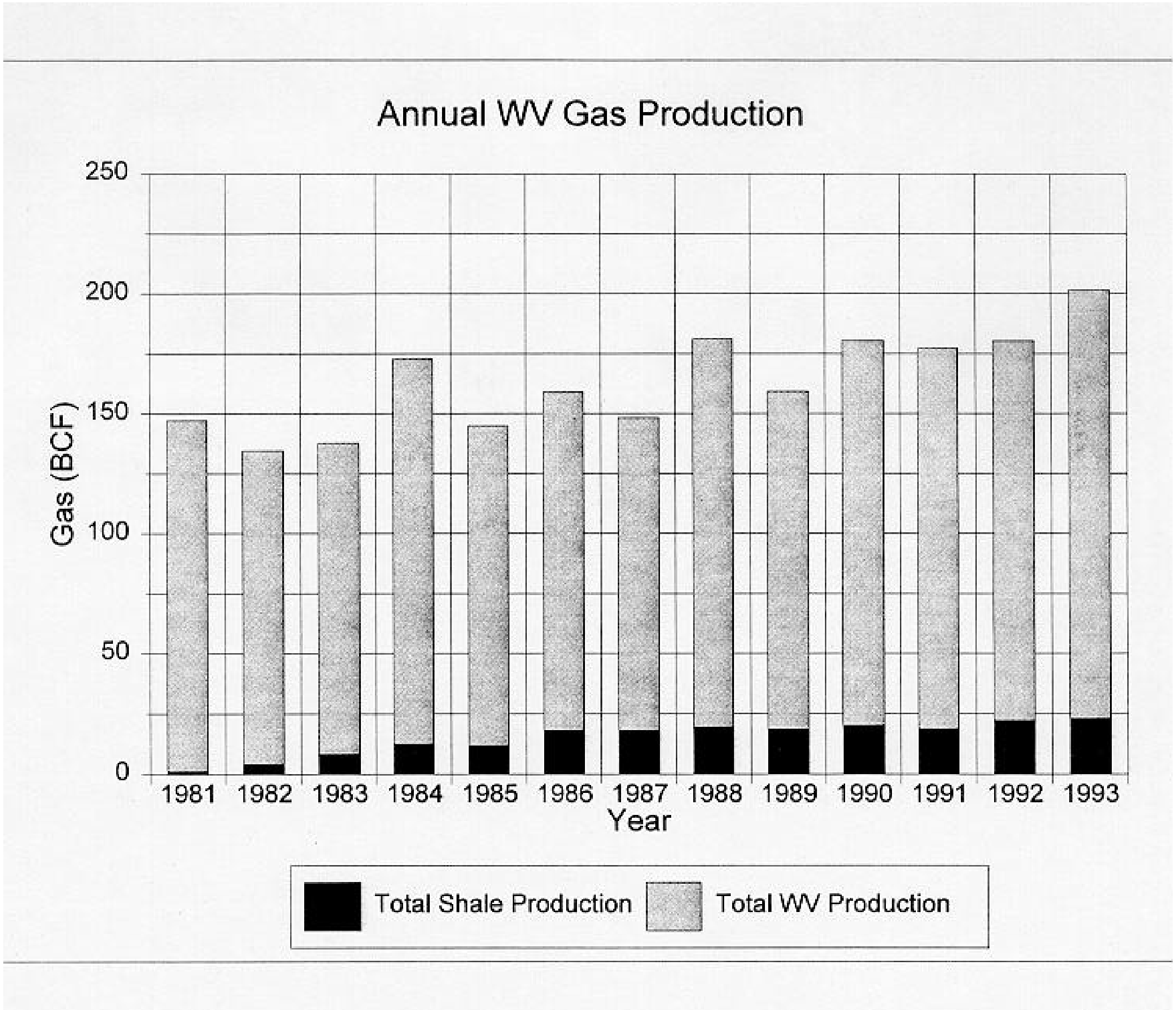

FIGURE 3. Annual gas production for all West Virginia gas wells and for all West Virginia Devonian shale wells, for the period from January, 1981 to December, 1993.

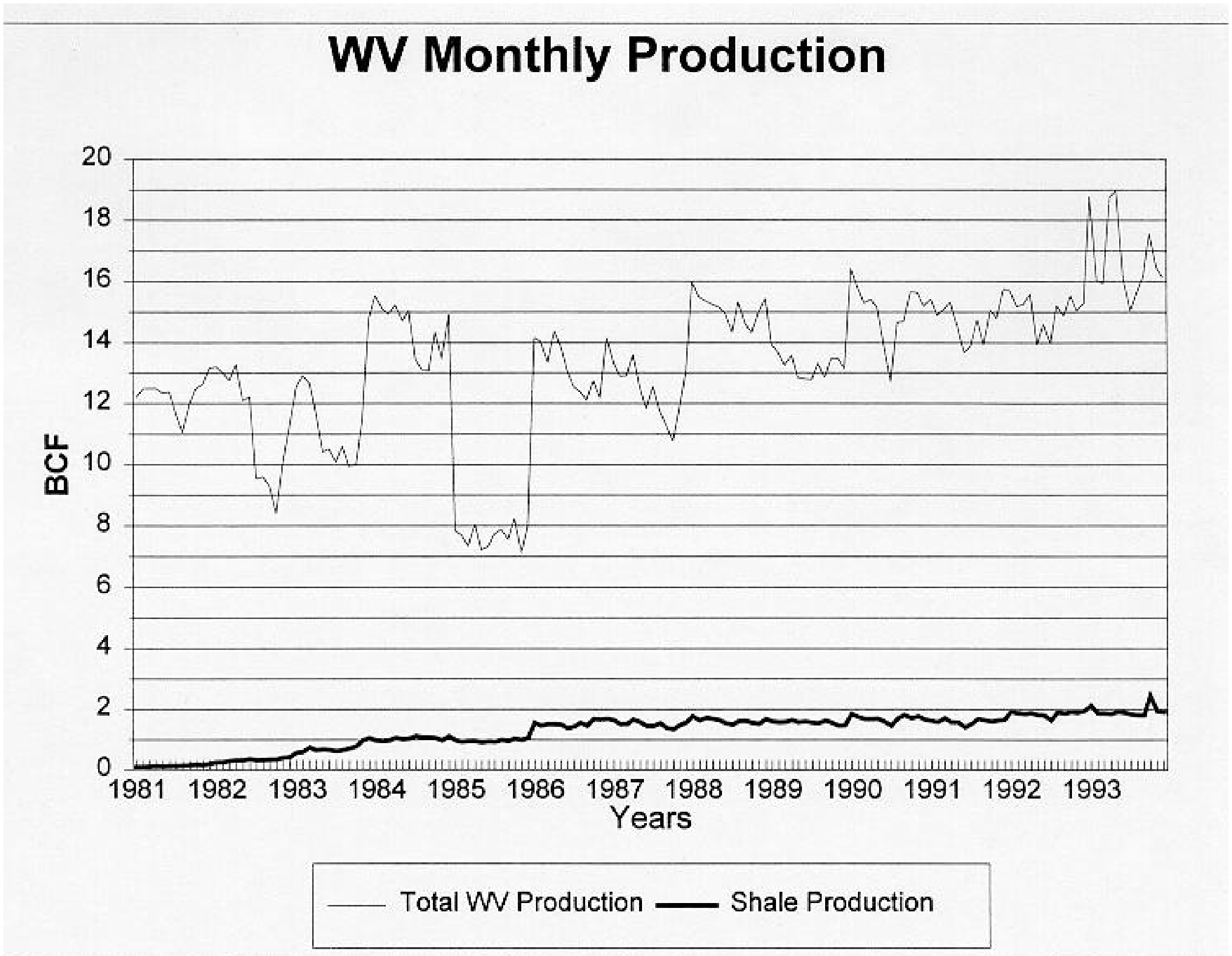

FIGURE 4. Total monthly gas production for all West Virginia gas wells and for West Virginia Devonian shale wells, for the period from January, 1981 to December, 1993.

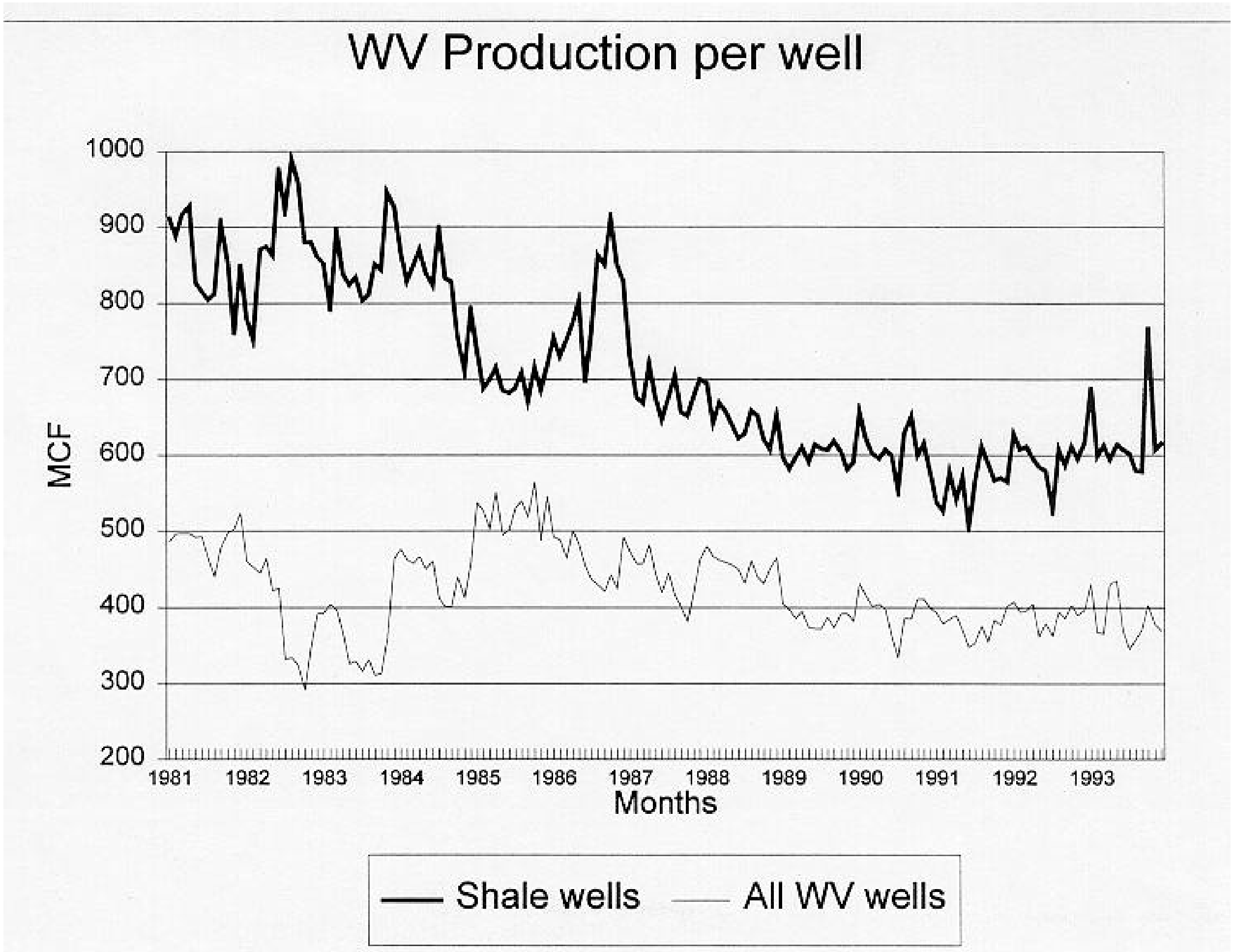

FIGURE 5. West Virginia gas production per well for all West Virginia wells and for West Virginia Devonian shale wells, for the years 1981 - 1993.

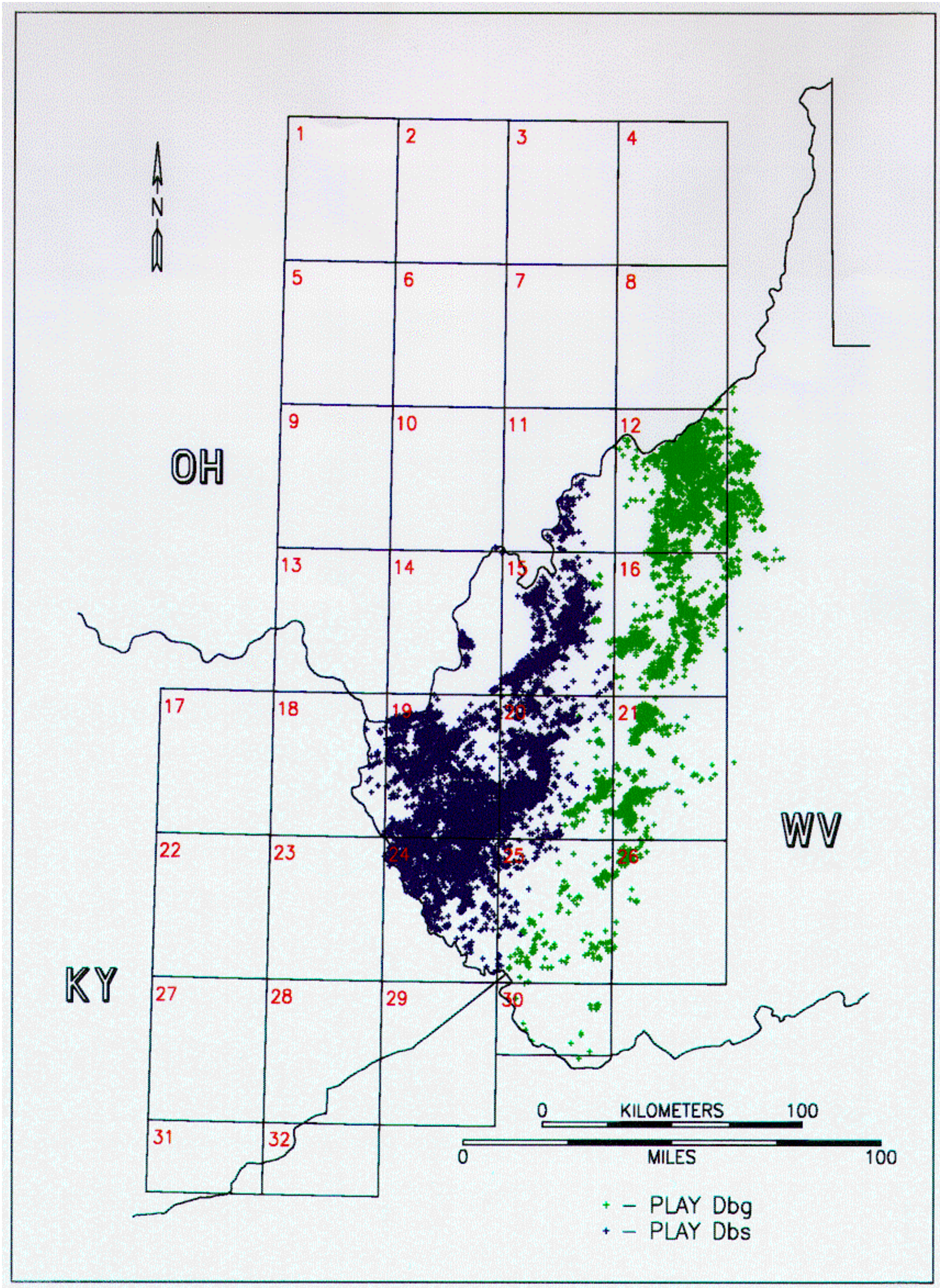

FIGURE 6 Locations of GRI cells 1 - 32 and all wells assigned to Gas Atlas Plays Dbg (Devonian black/gray shales and siltstones) and Dbs (Devonian black shales).

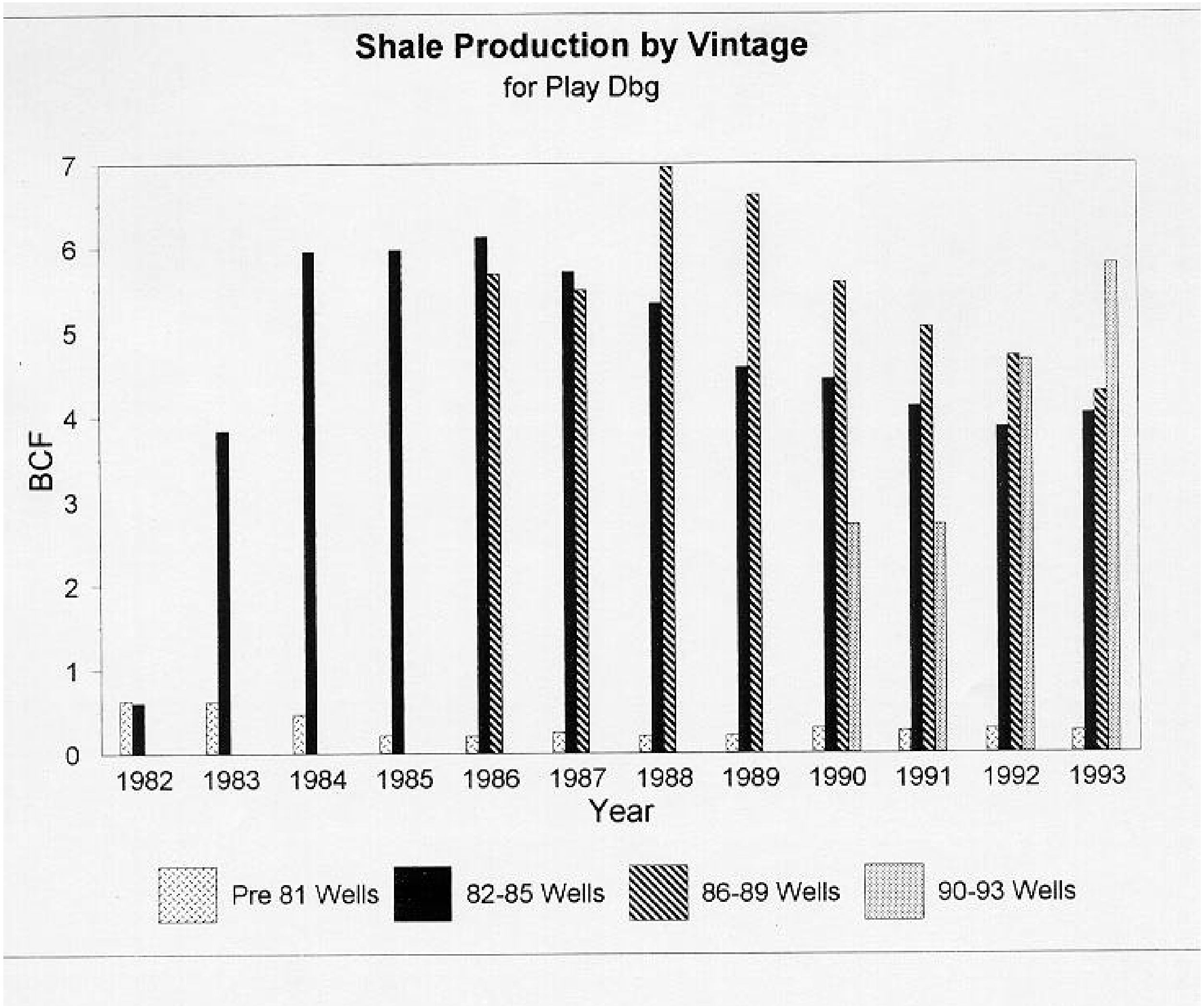

FIGURE 7. Bar graph of reported gas production for West Virginia Devonian shale wells, subdivided by vintage or the year in which the wells were originally completed.

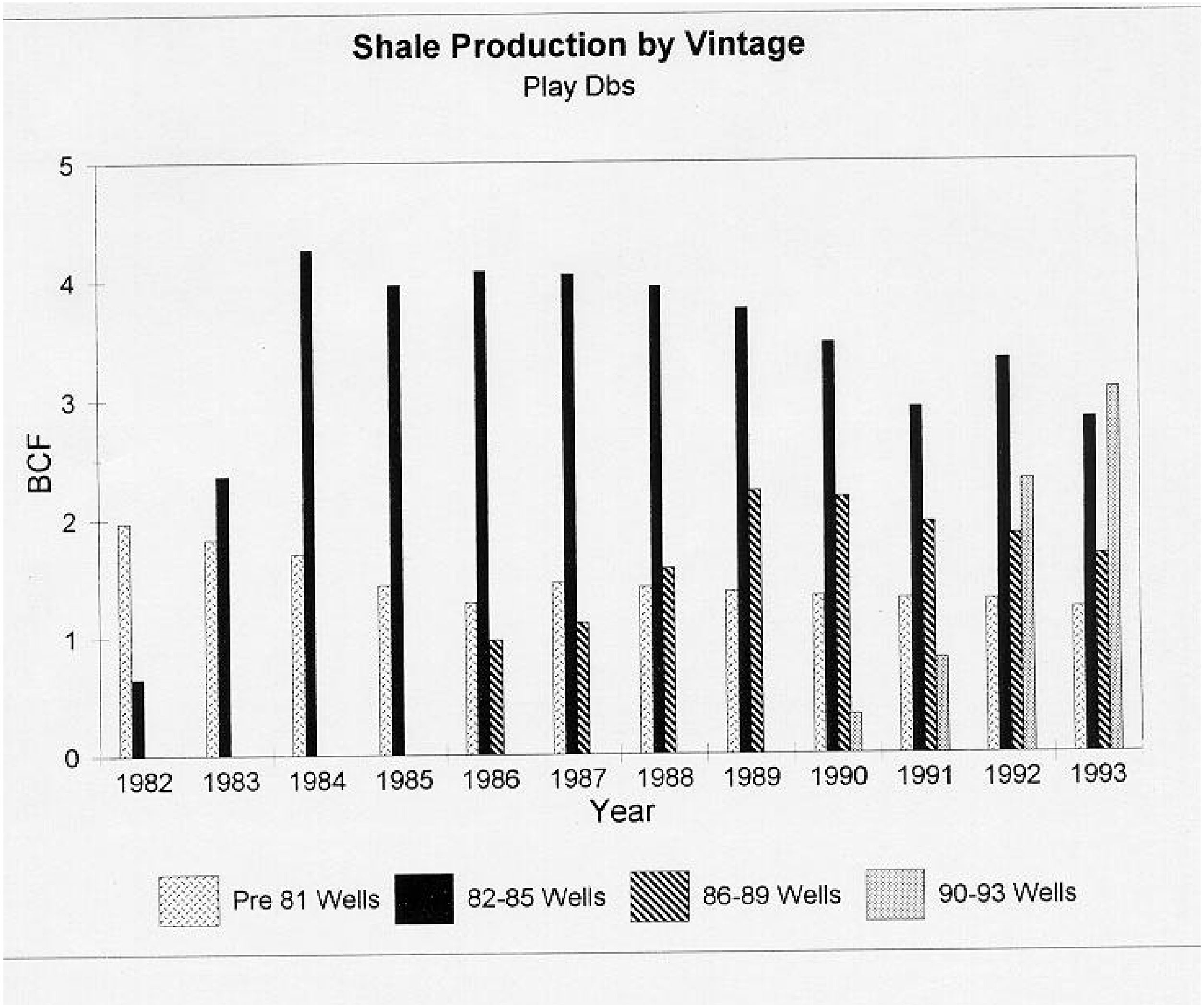

FIGURE 8. Bar graph of reported gas production for West Virginia Devonian shale wells, subdivided by vintage, or year of completion and also by Gas Atlas play (Play Dbg - black and gray shales and siltstones; and Dbs - black shales). The data are summed for the periods prior to 1981, 1982-1985, 1986-1989, and 1990-1993.

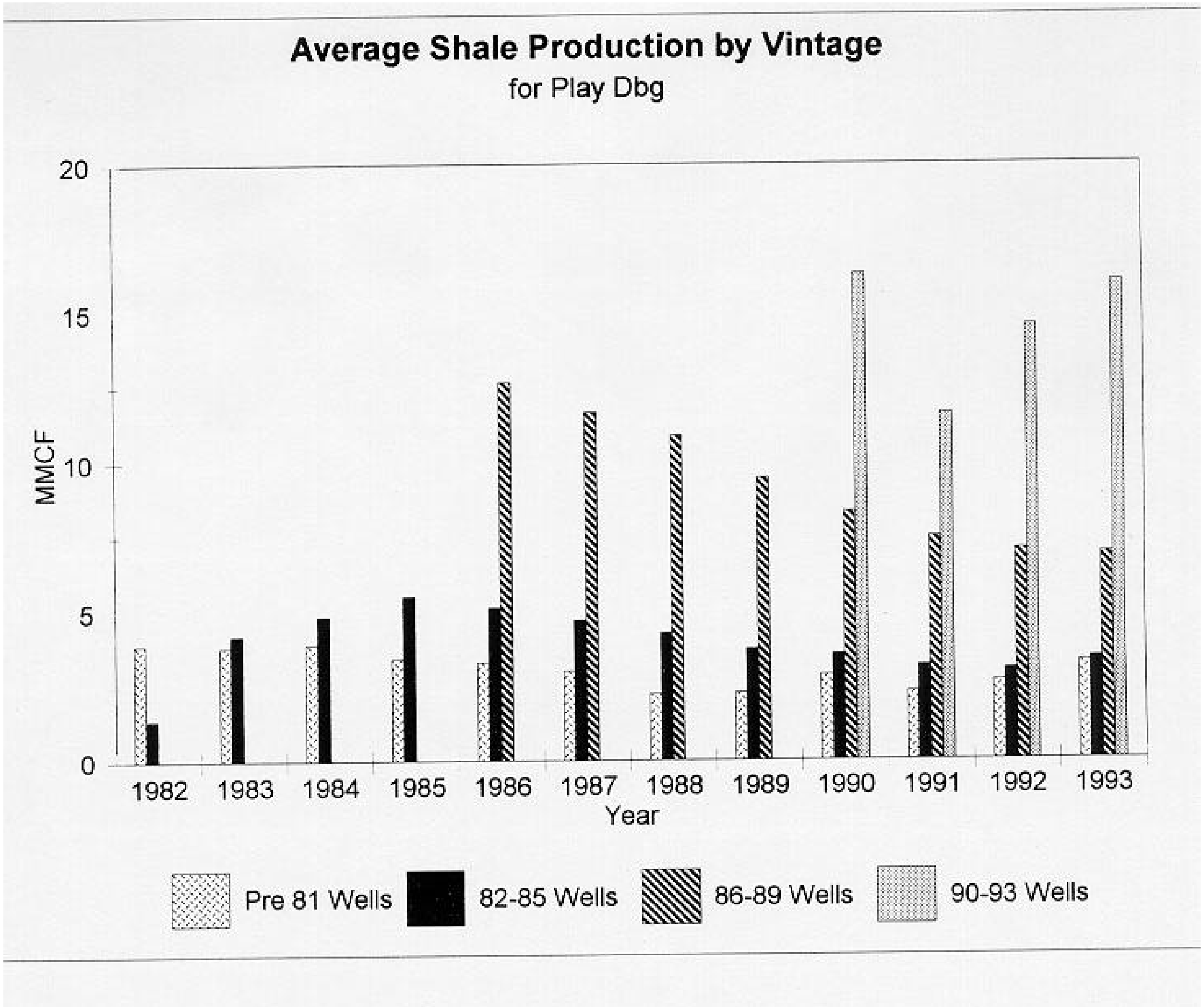

FIGURE 9. Average annual reported gas production per well, for West Virginia Devonian shale wells, subdivided by vintage, or year of completion, for the periods prior to 1981, 1982-1985, 1986-1989, and 1990-1993.

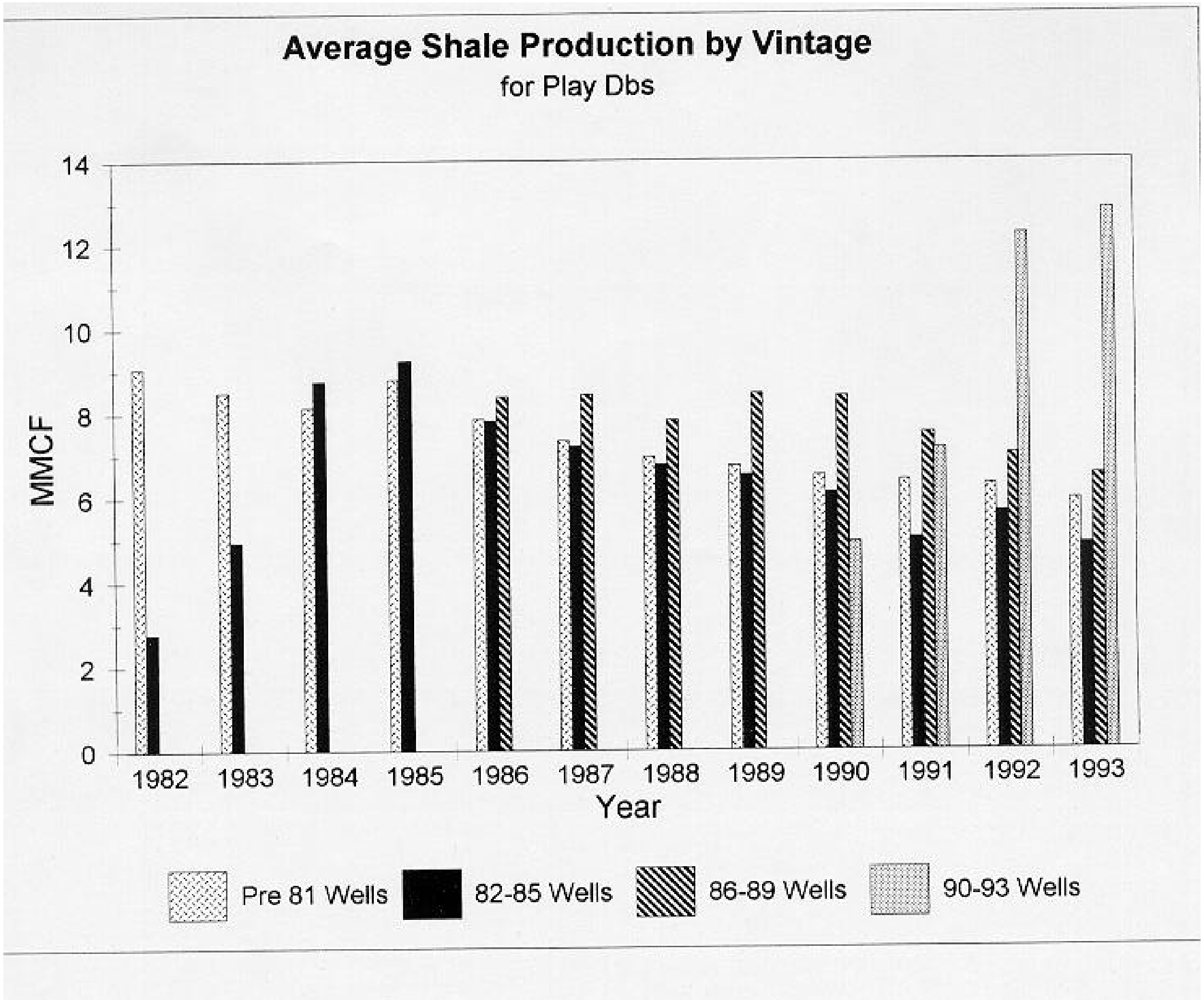

FIGURE 10. Average annual reported gas production for West Virginia Devonian shale wells, subdivided by vintage, or year of completion, and also by Gas Atlas play (Play Dbg, black and gray shales and siltstones; and Dbs, black shales). The data are summed for the periods prior to 1981, 1982-1985, 1986-1989, and 1990-1993.

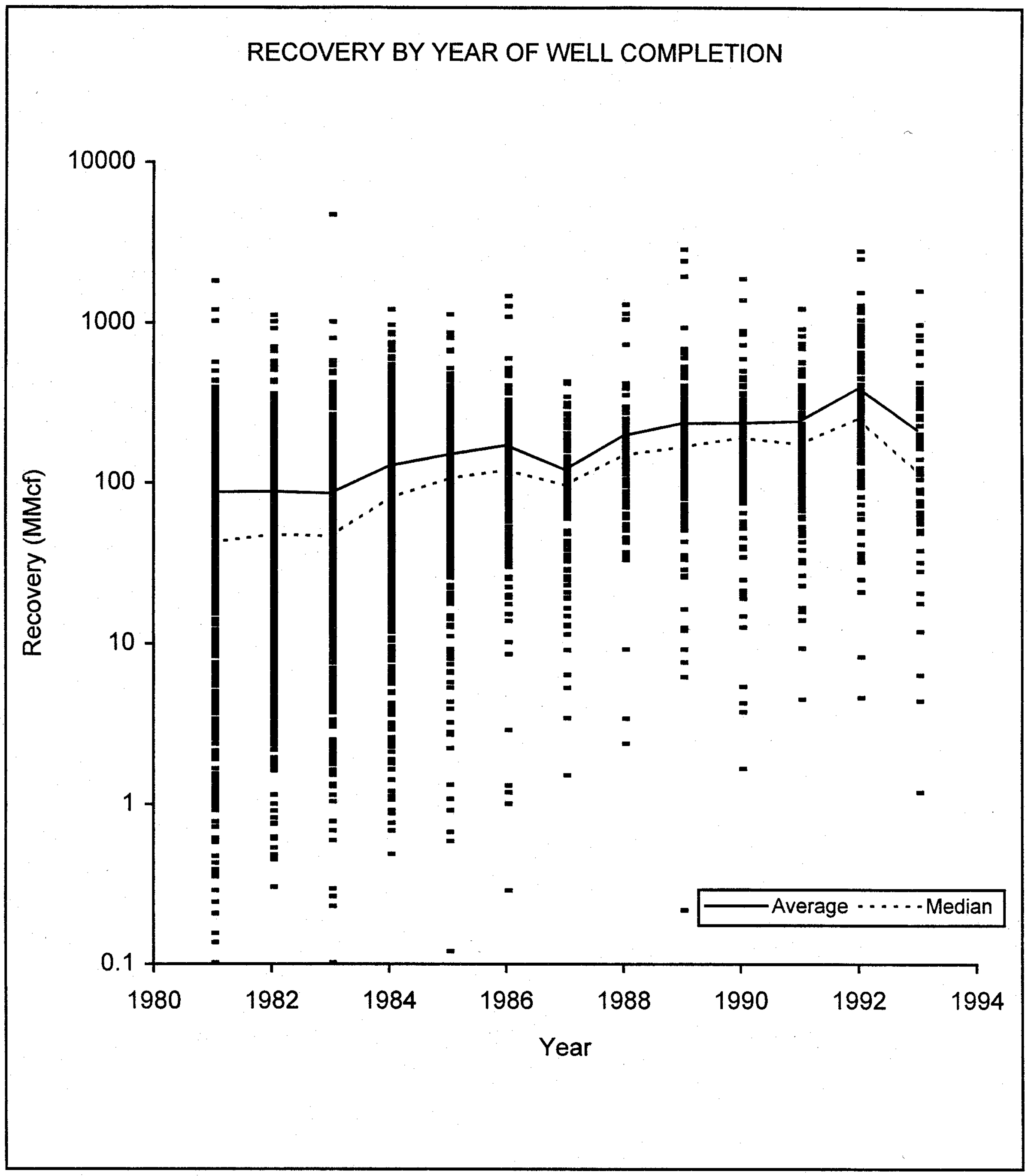

FIGURE 11. Gas recovery versus year of completion for Devonian shale wells completed between 1981 and 1993.

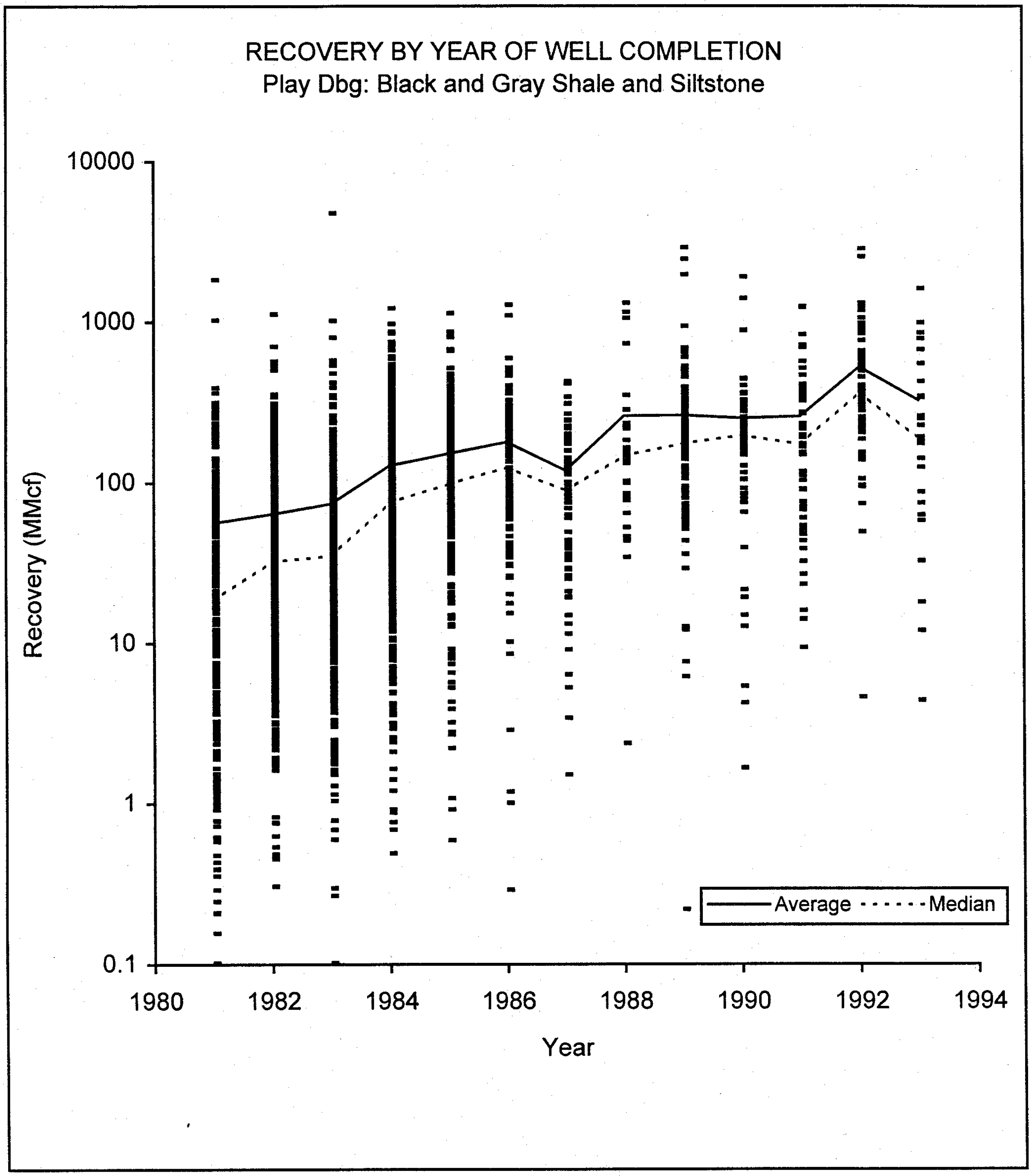

FIGURE 12. Gas recovery versus year of completion for Devonian shale wells completed between 1981 and 1993 in Gas Atlas Play Dbg (black and gray shales and siltstones).

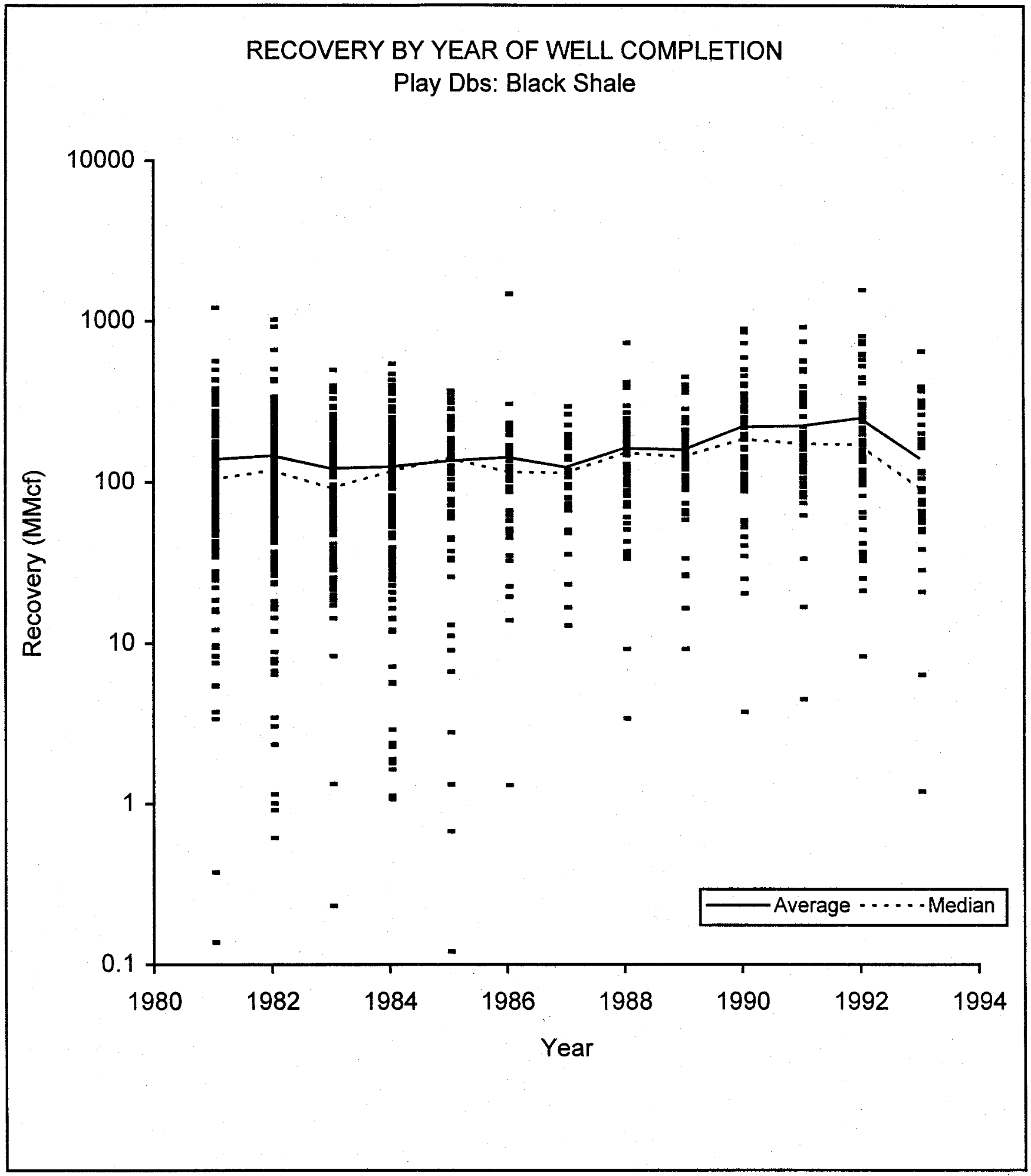

FIGURE 13. Gas recovery versus year of completion for Devonian shale wells completed between 1981 and 1993 in Gas Atlas Play Dbs (black shales).

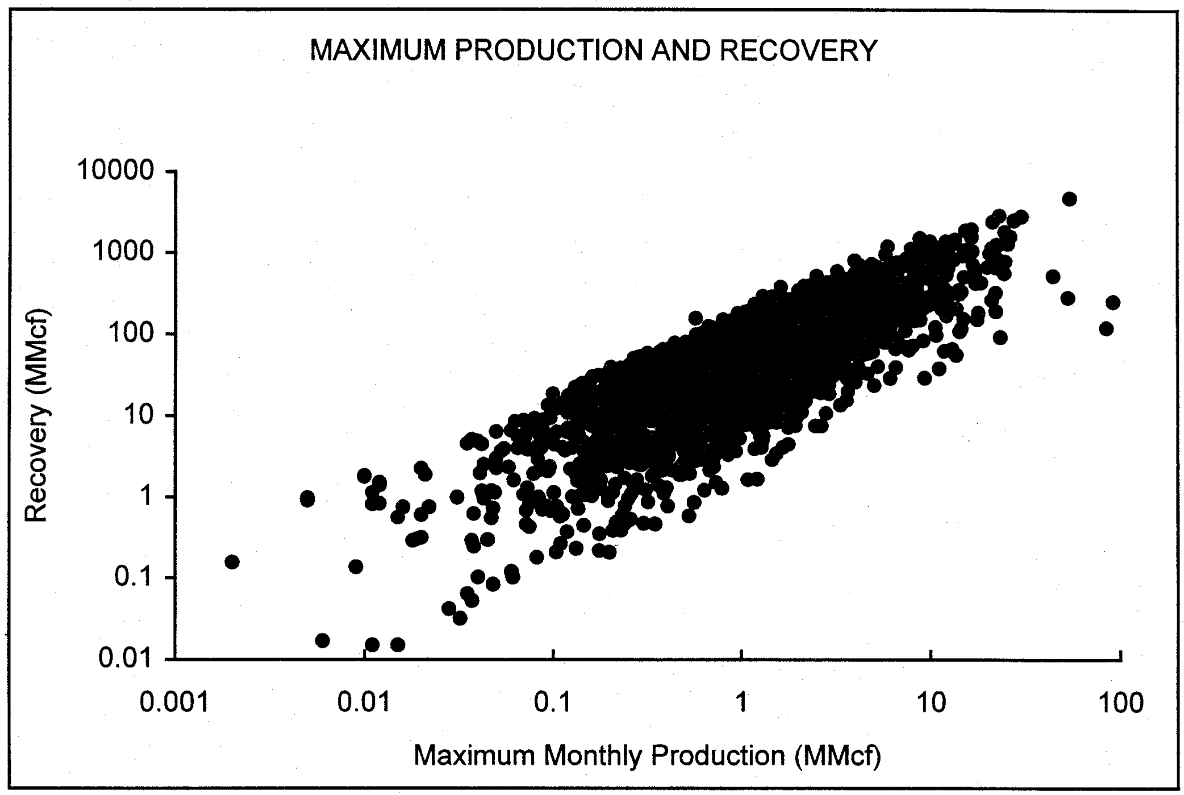

FIGURE 14. Maximum monthly gas production and gas recovery for Devonian shale wells completed between 1981 and 1993.

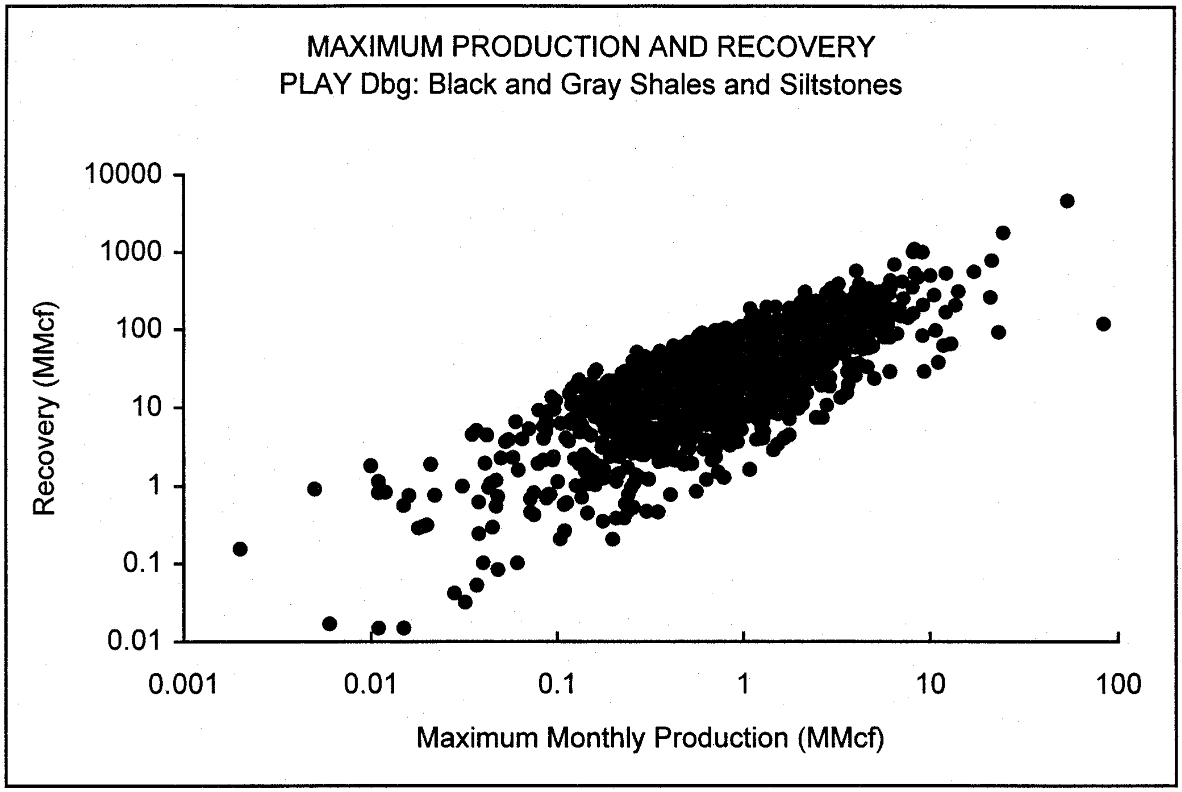

FIGURE 15. Maximum monthly gas production and gas recovery for Devonian shale wells completed between 1981 and 1993 in Gas Atlas Play Dbg (black and gray shales and siltstones).

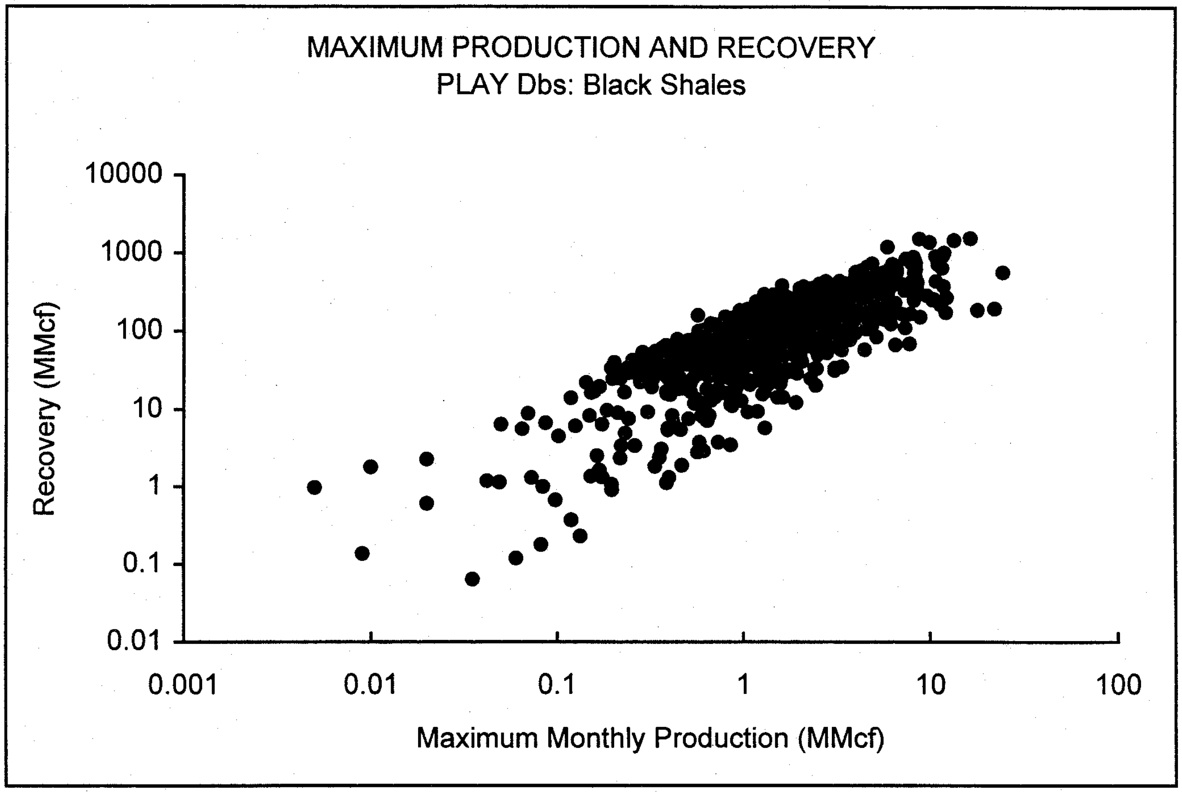

FIGURE 16. Maximum monthly gas production and gas recovery for Devonian shale wells completed between 1981 and 1993 in Gas Atlas Play Dbs (black shales).

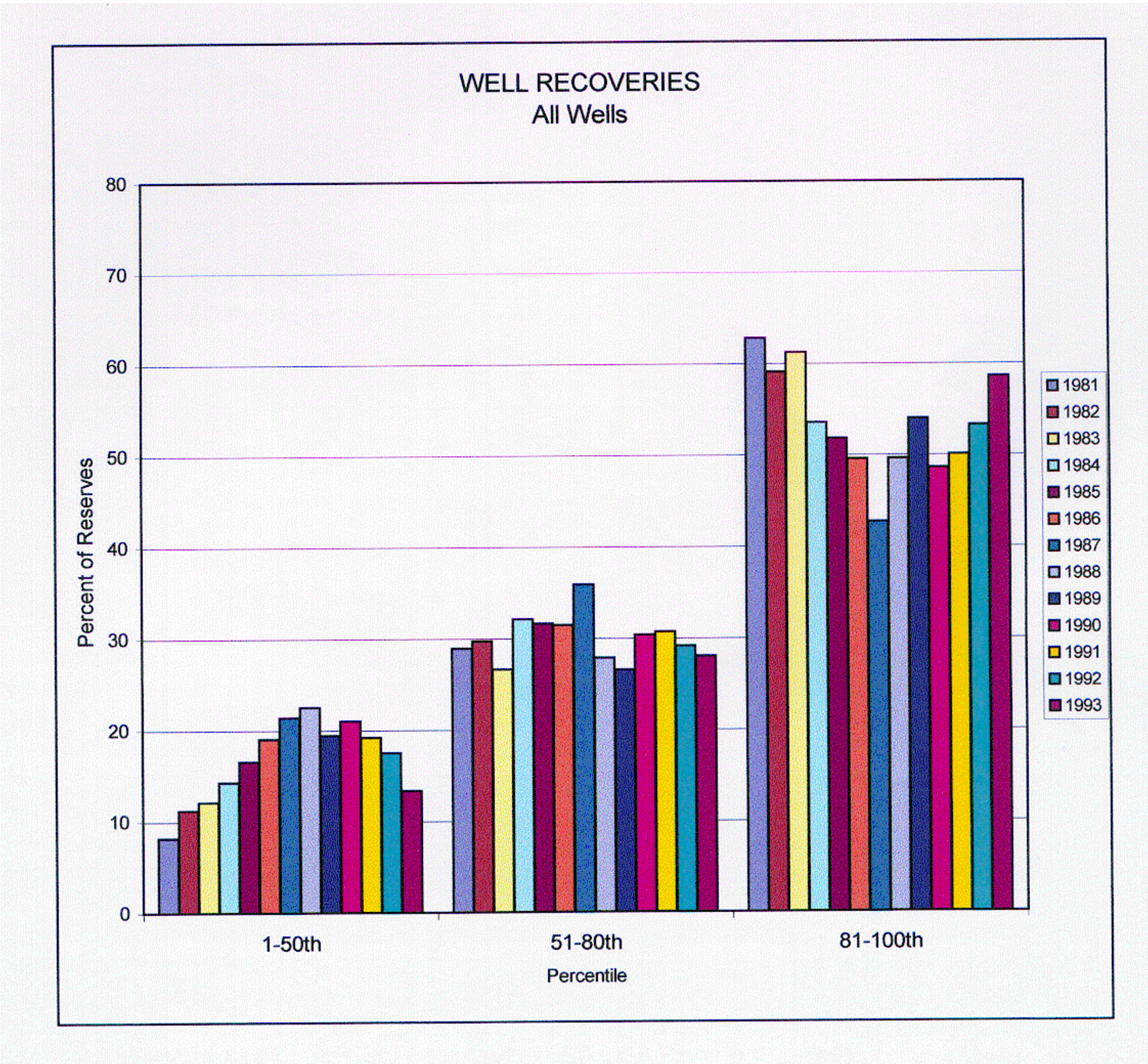

FIGURE 17. Percent of reserves accounted for by wells with recovery below each of three percentiles.

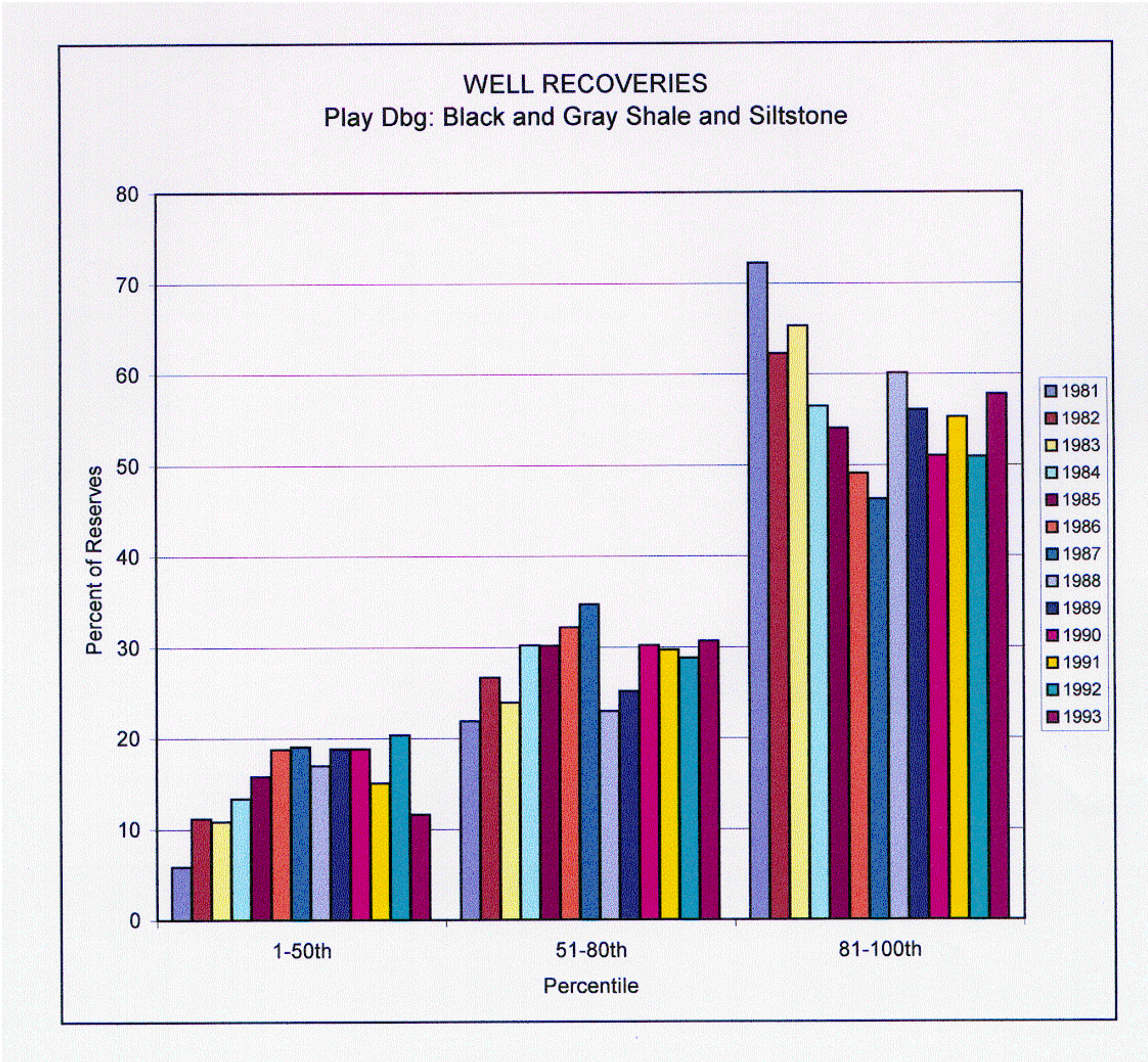

FIGURE 18. Percent of reserves accounted for by wells with recovery below each of three percentiles in Gas Atlas Play Dbg (black and gray shales and siltstones).

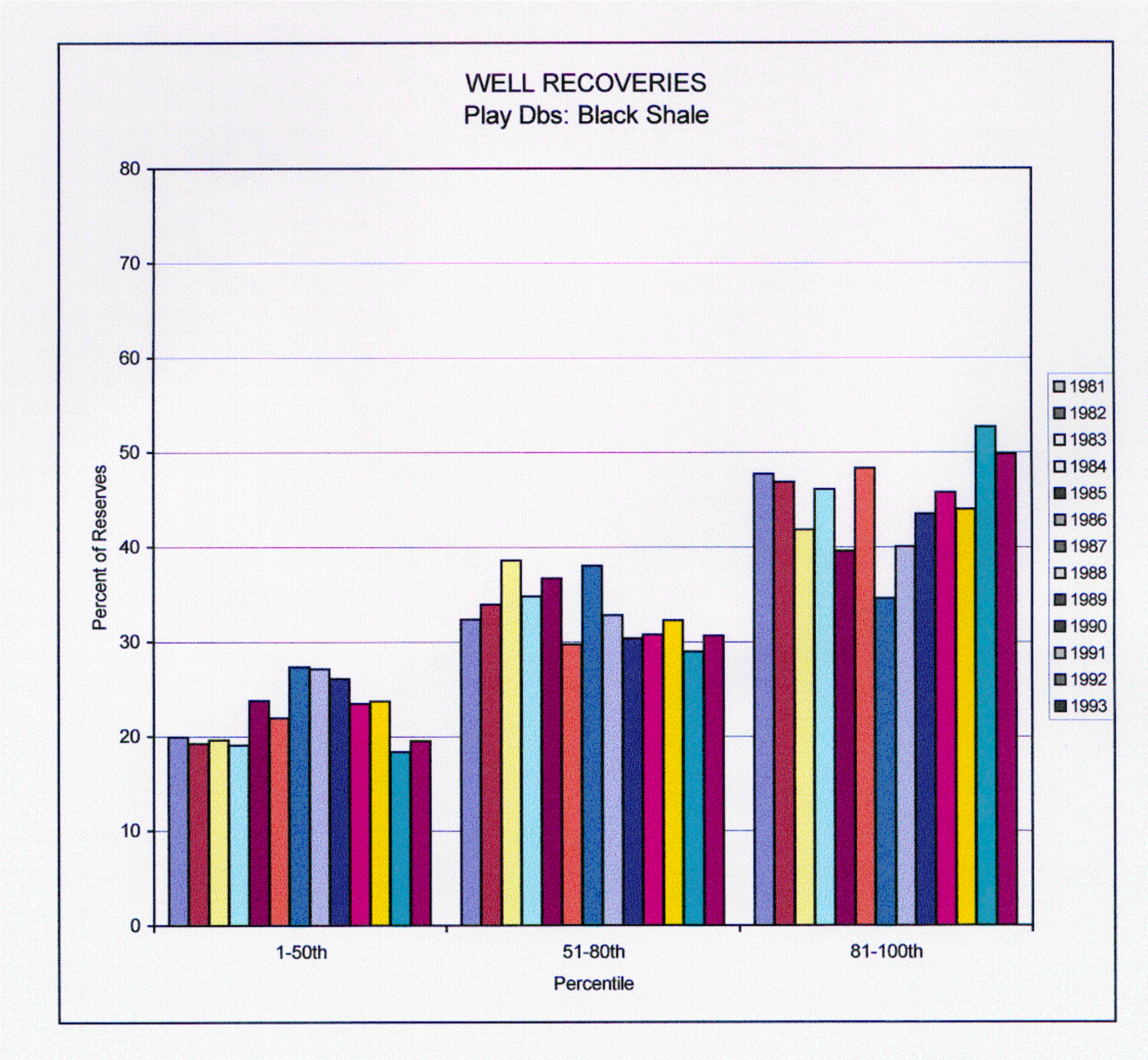

FIGURE 19. Percent of reserves accounted for by wells with recovery below each of three percentiles in Gas Atlas Play Dbs (black shales).

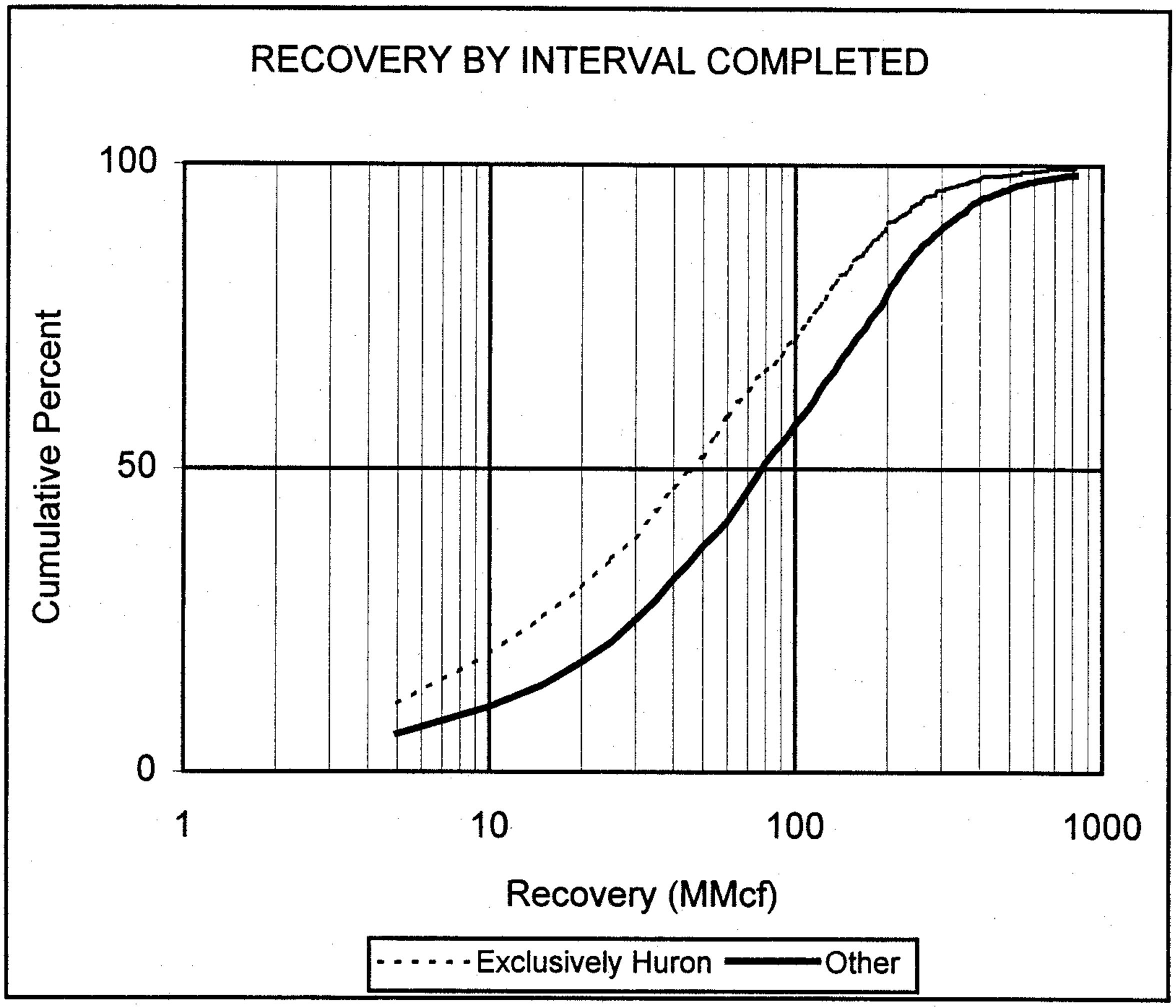

FIGURE 20. Gas recovery for shale wells completed between 1981 and 1993.

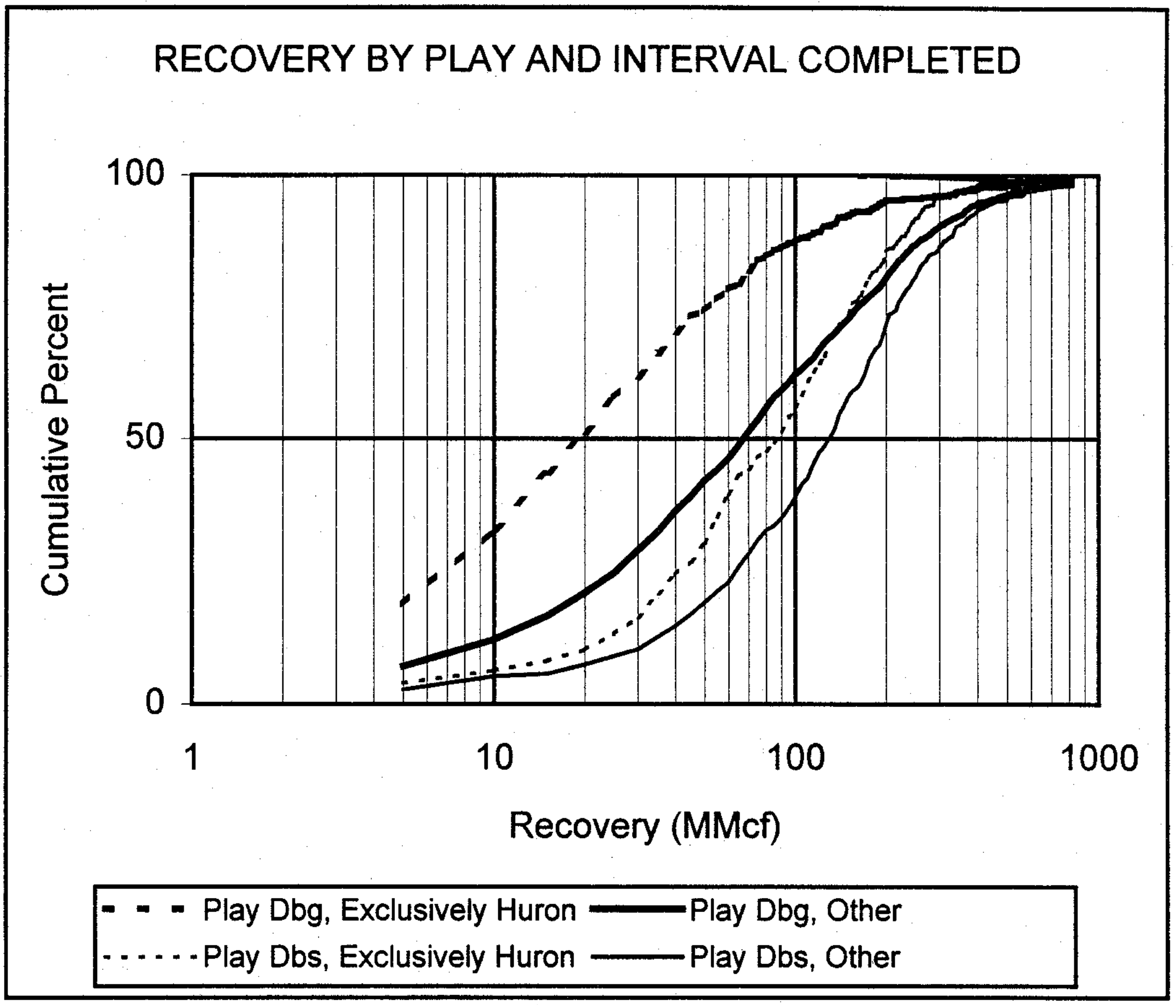

FIGURE 21. Gas recovery for Devonian shale wells completed between 1981 and 1993. Wells are separated into those completed only in the Lower Huron Member of the Ohio Shale (Exclusively Huron) and those completed in other Devonian shale zones beside and perhaps including the Lower Huron Member of the Ohio Shale (Other). They are also separated by Gas Atlas play; Play Dbg is the black shales and siltstones, and Play Dbs is the black shales.

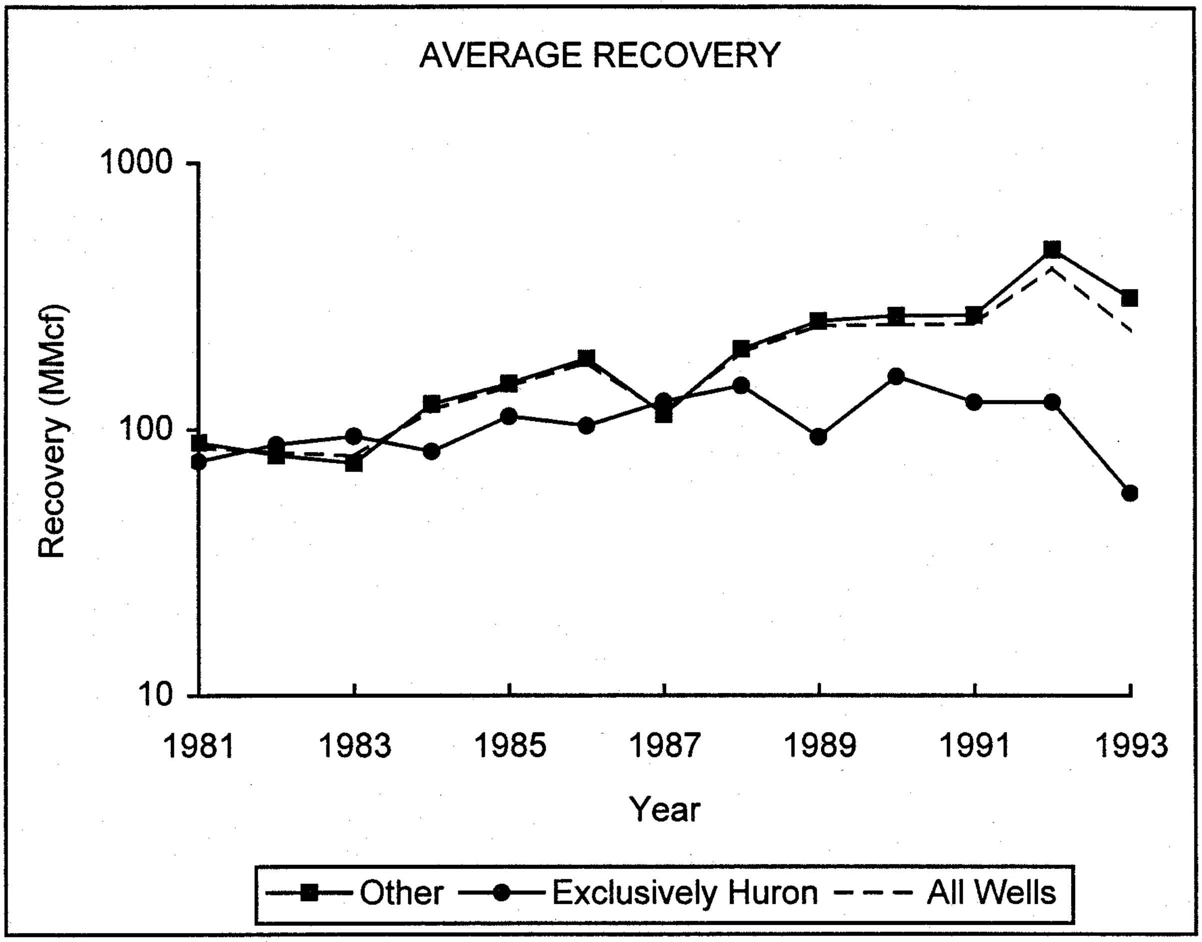

FIGURE 22. Average gas recovery for Devonian shale wells completed between 1981 and 1993.

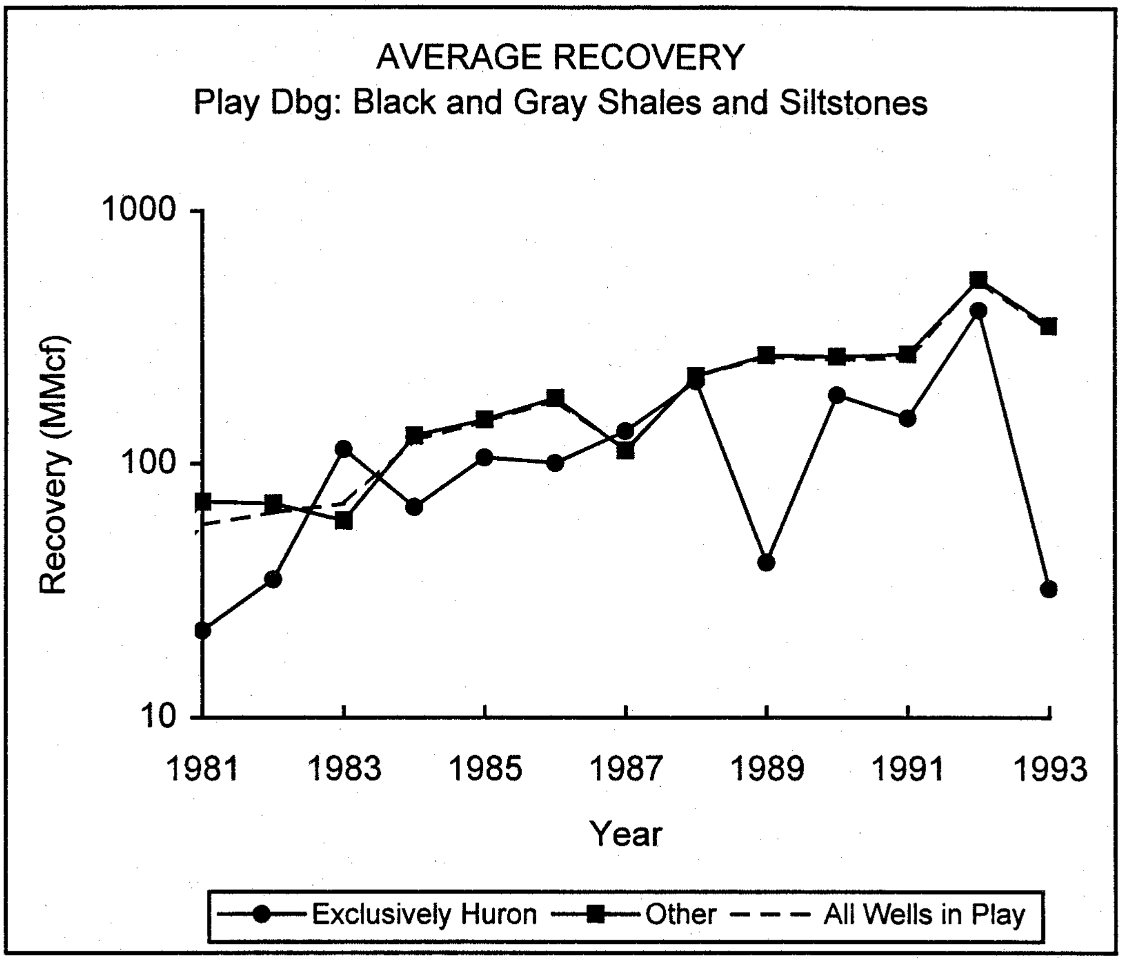

FIGURE 23. Average gas recovery for Devonian shale wells completed between 1981 and 1993 in Gas Atlas Play Dbg (black and gray shales and siltstones).

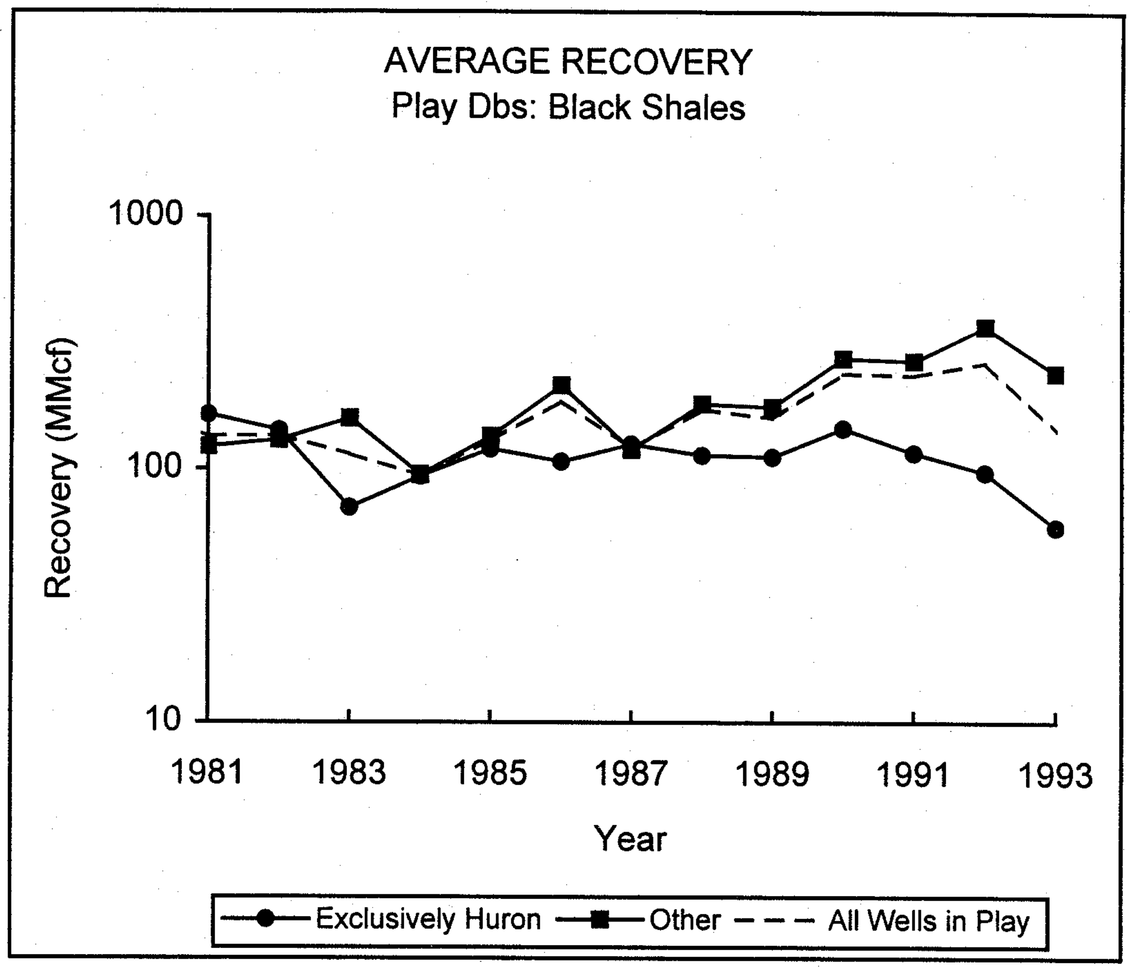

FIGURE 24. Plot of average gas recovery for West Virginia Devonian shale wells completed between 1981 and 1993 in Gas Atlas Play Dbs (black shales).

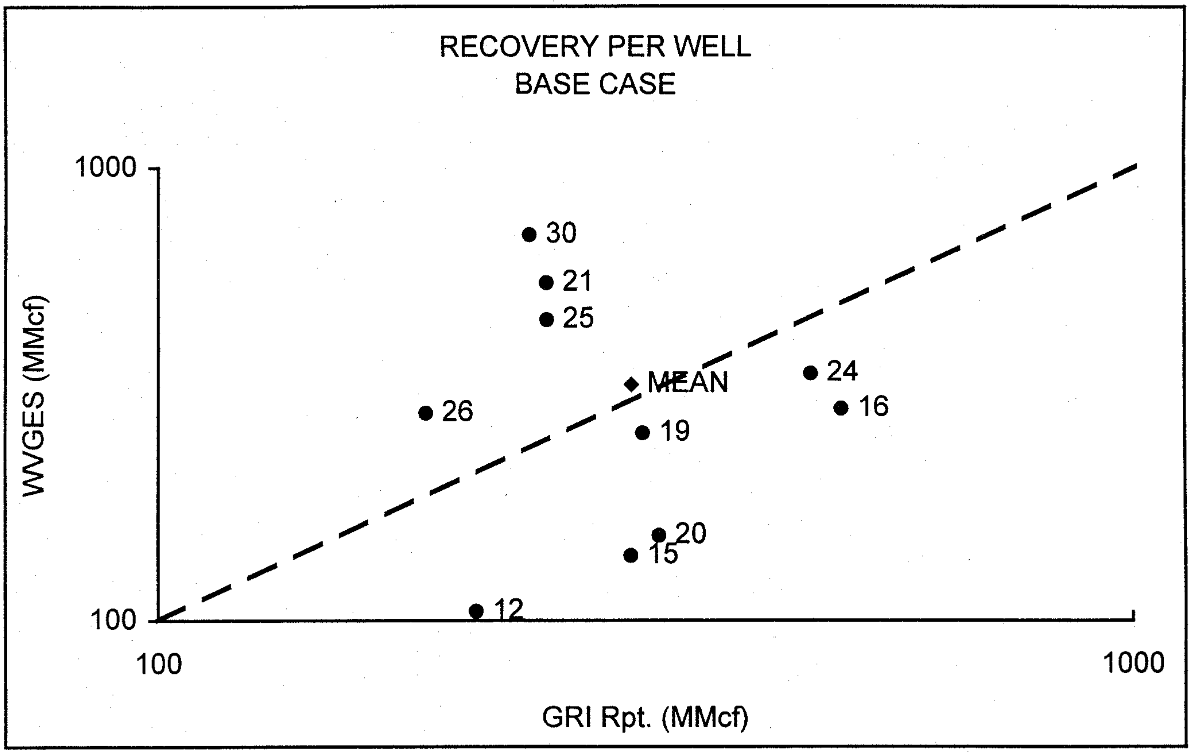

FIGURE 25. Average gas recovery per well for the base case in the existing GRI model versus average gas recovery per well calculated by the West Virginia Geological and Economic Survey (WVGES). Locations of cells are shown on Figure 6.

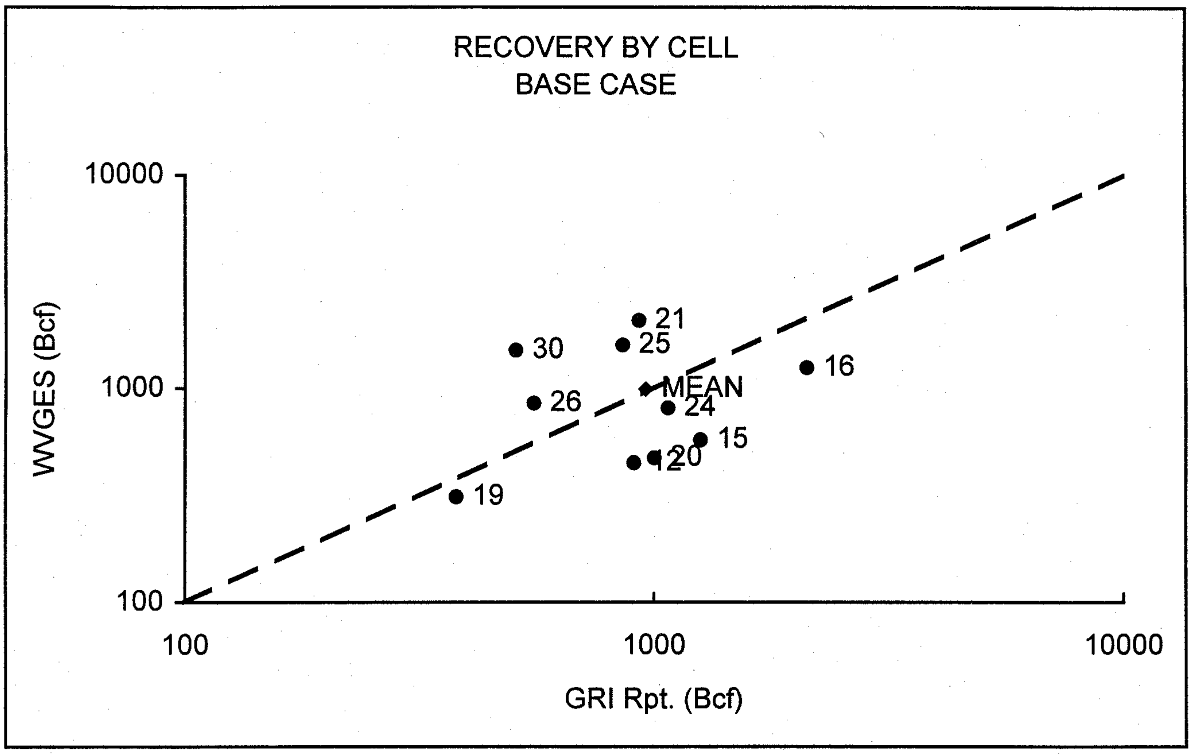

FIGURE 26. Total gas recovery for the base case in the existing GRI model versus gas recovery calculated by the West Virginia Geological and Economic Survey (WVGES). Locations of cells are shown on Figure 6.

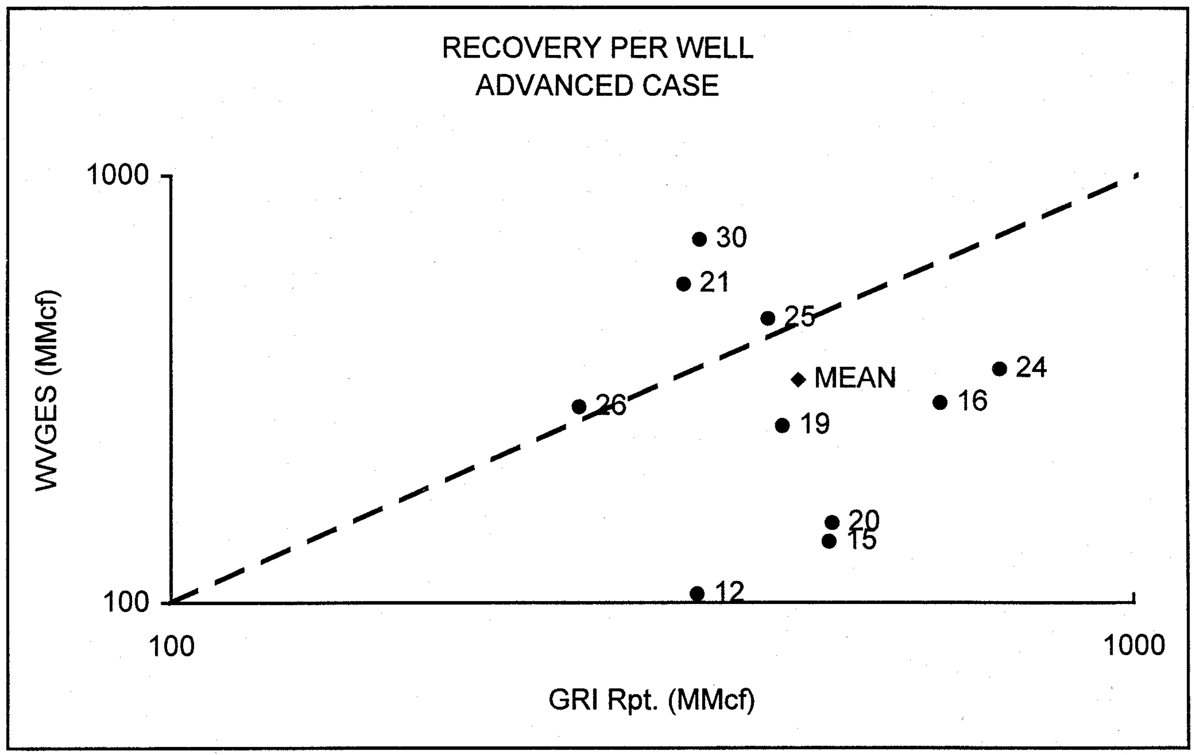

FIGURE 27. Average gas recovery per well for the advanced case in the existing GRI model versus average gas recovery per well calculated by the West Virginia Geological and Economic Survey (WVGES). Locations of cells are shown on Figure 6.

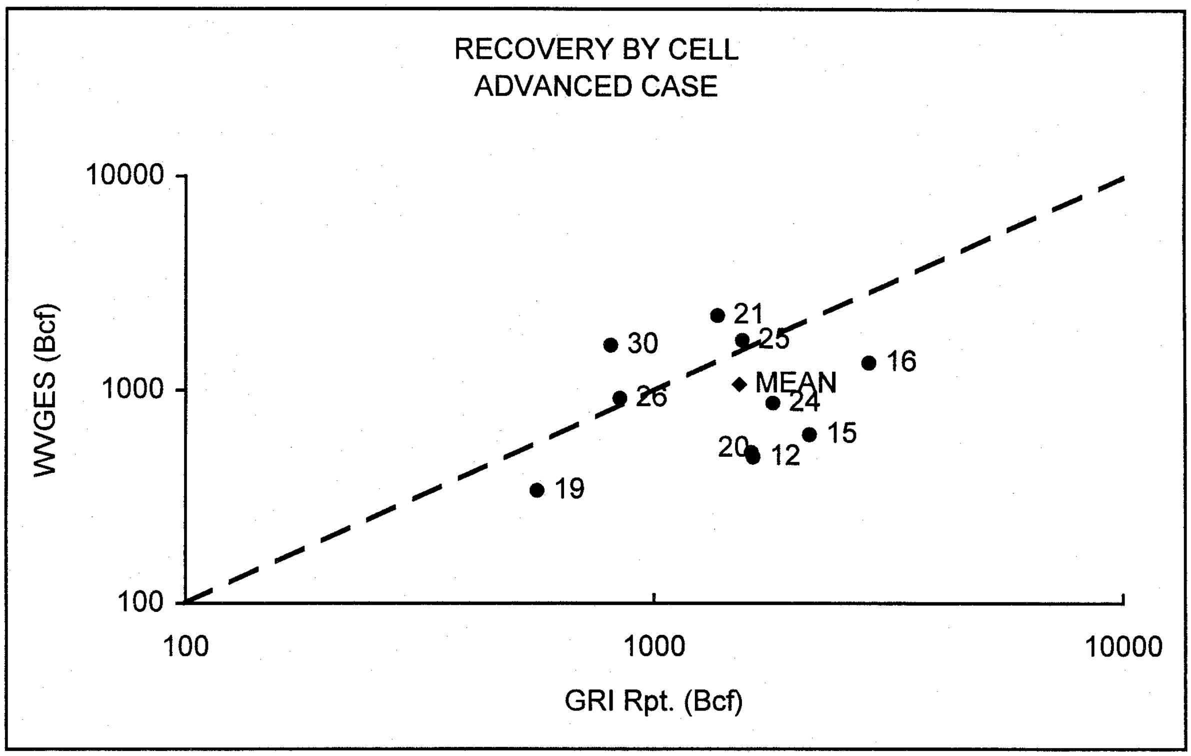

FIGURE 28. Total gas recovery for the advanced case in the existing GRI model versus gas recovery calculated by the West Virginia Geological and Economic Survey (WVGES). Locations of cells are shown on Figure 6.

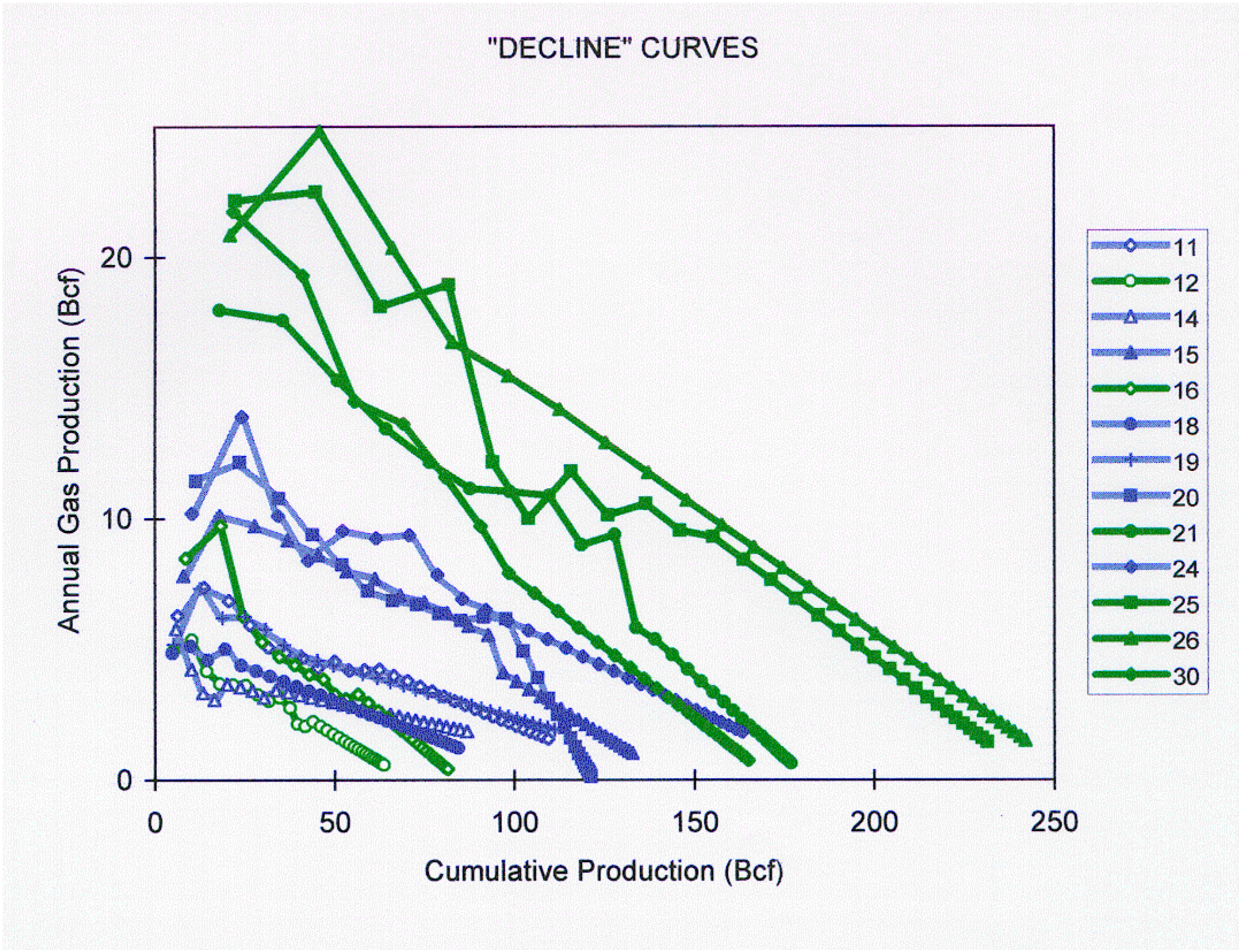

FIGURE 29. Decline curves showing average annual production versus cumulative production of reach cell in Figure 6.

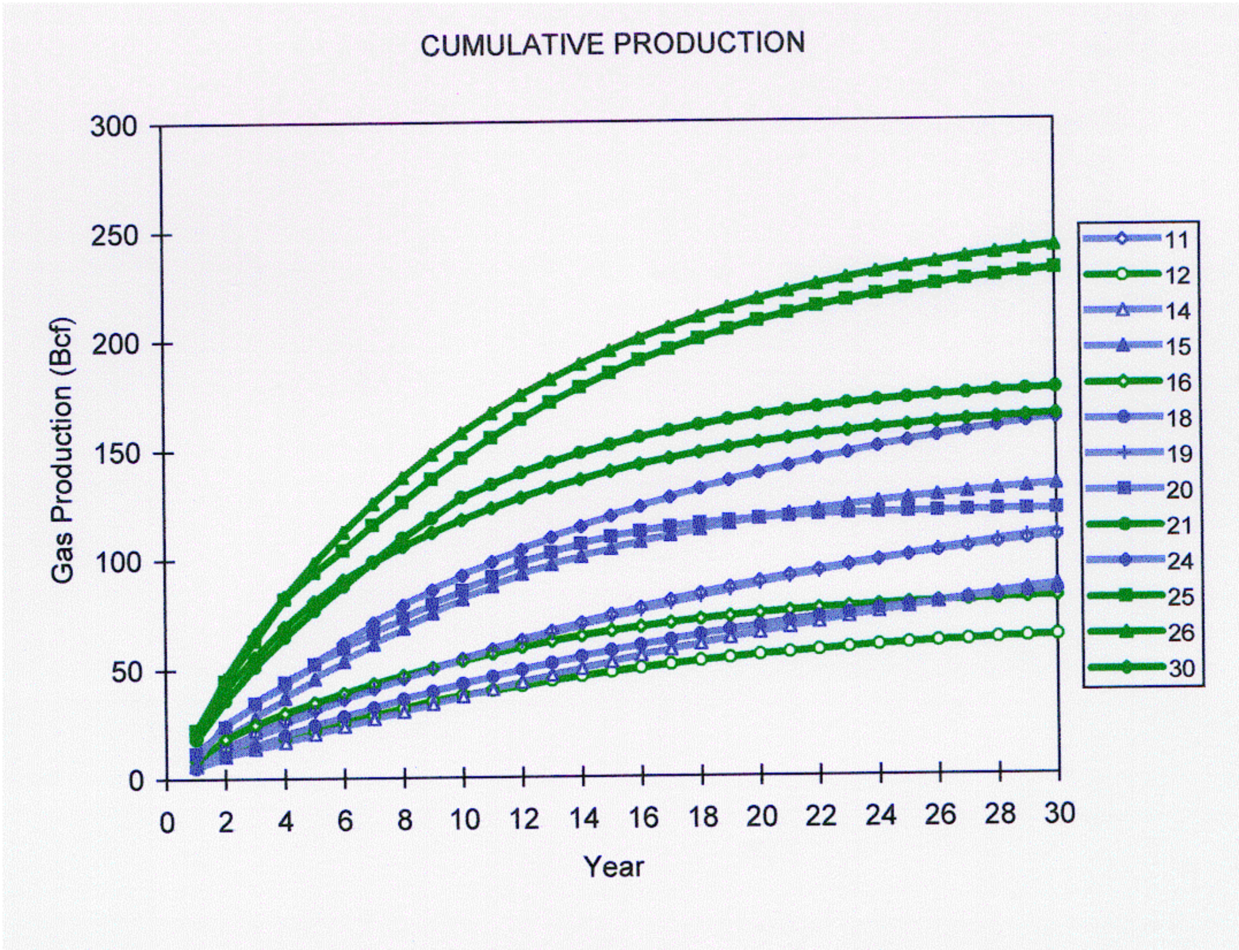

FIGURE 30. Total cumulative production in each cell. Locations of cells are shown on Figure 6.