Ronald R. Charpentier
(charpentier@usgs.gov)
Troy A. Cook
(tcook@usgs.gov)
U.S. Geological Survey
Box 25046, MS 939
Denver, CO 80225

Variability of Oil and Gas Well Productivities for Continuous (Unconventional) Petroleum Accumulations

By Ronald R. Charpentier and Troy A. Cook

2013

Abstract

Over the last decade, oil and gas well productivities were estimated using decline-curve analysis for thousands of wells as part of U.S. Geological Survey (USGS) studies of continuous (unconventional) oil and gas resources in the United States. The estimated ultimate recoveries (EURs) of these wells show great variability that was analyzed at three scales: within an assessment unit (AU), among AUs of similar reservoir type, and among groups of AUs with different reservoir types.

Within a particular oil or gas AU (such as the Barnett Shale), EURs vary by about two orders of magnitude between the most productive wells and the least productive ones (excluding those that are dry and abandoned). The distributions of EURs are highly skewed, with most of the wells in the lower part of the range.

Continuous AUs were divided into four categories based on reservoir type and major commodity (oil or gas): coalbed gas, shale gas, other low-permeability gas AUs (such as tight sands), and low-permeability oil AUs. Within each of these categories, there is great variability from AU to AU, as shown by plots of multiple EUR distributions. Comparing the means of each distribution within a category shows that the means themselves have a skewed distribution, with a range of approximately one to two orders of magnitude.

A comparison of the three gas categories (coalbed gas, shale gas, and other low-permeability gas AUs) shows large overlap in the ranges of EUR distributions. Generally, coalbed gas AUs have lower EUR distributions, shale gas AUs have intermediate sizes, and the other low-permeability gas AUs have higher EUR distributions.

The plot of EUR distributions for each category shows the range of variation among developed AUs in an appropriate context for viewing the historical development within a particular AU. The Barnett Shale is used as an example to demonstrate that dividing wells into groups by time allows one to see the changes in EUR distribution. Subdivision into groups can also be done by vertical versus horizontal wells, by length of horizontal completion, by distance to closest previously drilled well, by thickness of reservoir interval, or by any other variable for which one has or can calculate values for each well. The resulting plots show how one can subdivide the total range of productivity in shale-gas wells into smaller subsets that are more appropriate for use as analogs.

Data Sources

IHS ENERGY, INC., MONTHLY PRODUCTION DATA FOR U.S. WELLS

50,000+ wells in continuous deposits studied

Estimated ultimate recovery (EUR) by decline-curve analysis

Decline-curve analysis done by hand or by automated procedures

USGS ASSESSMENTS OF CONTINUOUS RESOURCES IN THE UNITED STATES

132 assessments conducted from 2000 to 2011

Input forms give the estimated EUR distribution for the undrilled part of each assessment unit (AU)

EUR given as a shifted, truncated lognormal distribution

For most AUs, the EUR distribution for the undrilled portion of the AU is close to that for the drilled portion of the AU

EUR distribution from the input form takes into account geologic differences of undrilled versus drilled portions

Estimated Ultimate Recovery (EUR)

For each AU, tens to thousands of hand-fit decline curves to individual wells were used to create a distribution of EURs (Cook and Charpentier, 2010).

The use of automation and probabilistic expression to create probabilistic type curves may allow similar well-level results for more wells with a smaller time investment (Cook and Charpentier, 2010).
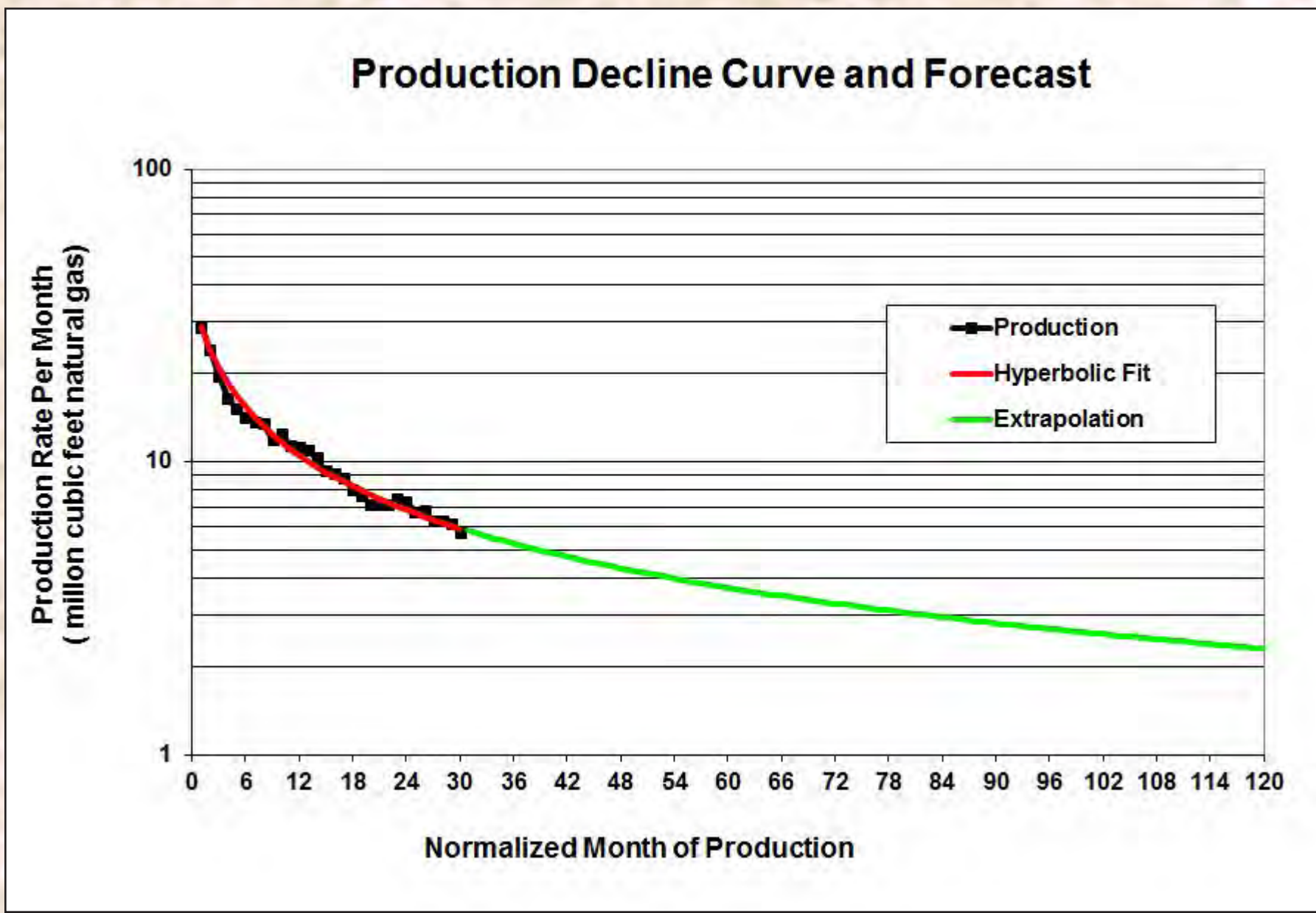

Figure 1. Example showing best-fit decline curve and extrapolation of decline to estimate EUR.
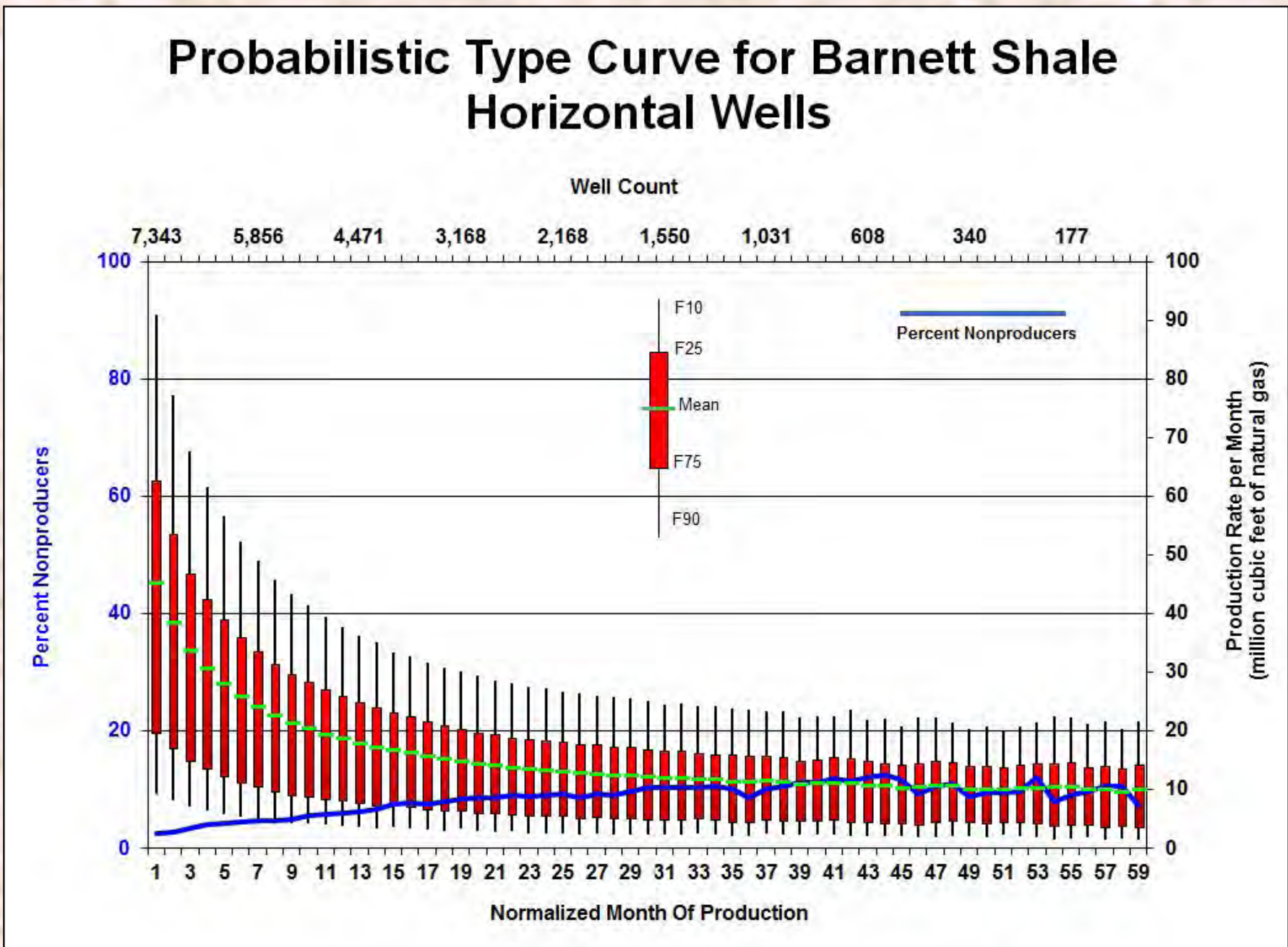

Figure 2. Example of a probabilistic type curve for Barnett Shale horizontal wells.

Either process delivers a single distribution of EURs for use in USGS continuous assessments.
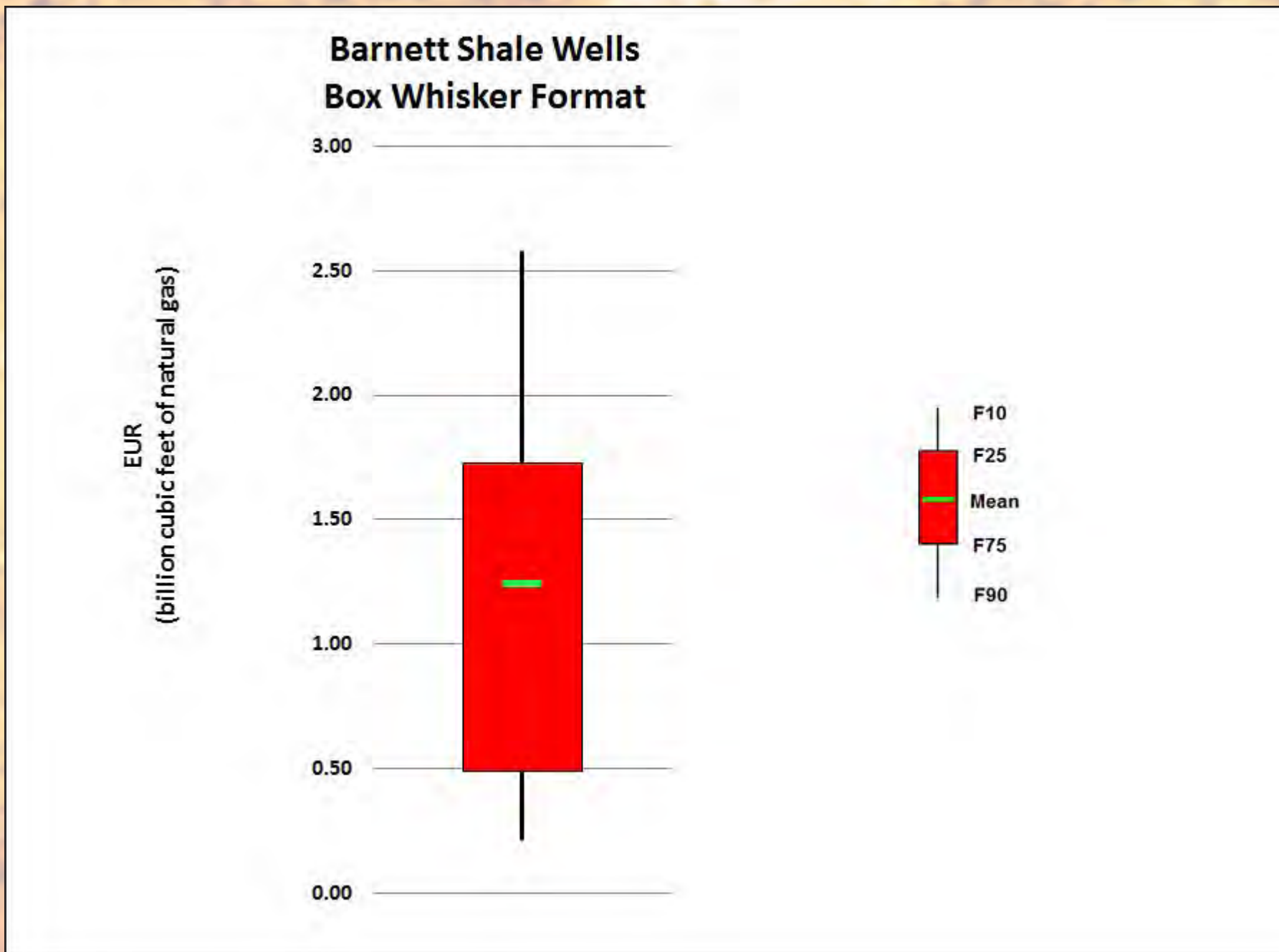

Figure 3. This box-whisker plot presents the EURs for all Barnett Shale wells drilled through October of 2009. (1 billion cubic feet equals approximately 28 million cubic meters.)
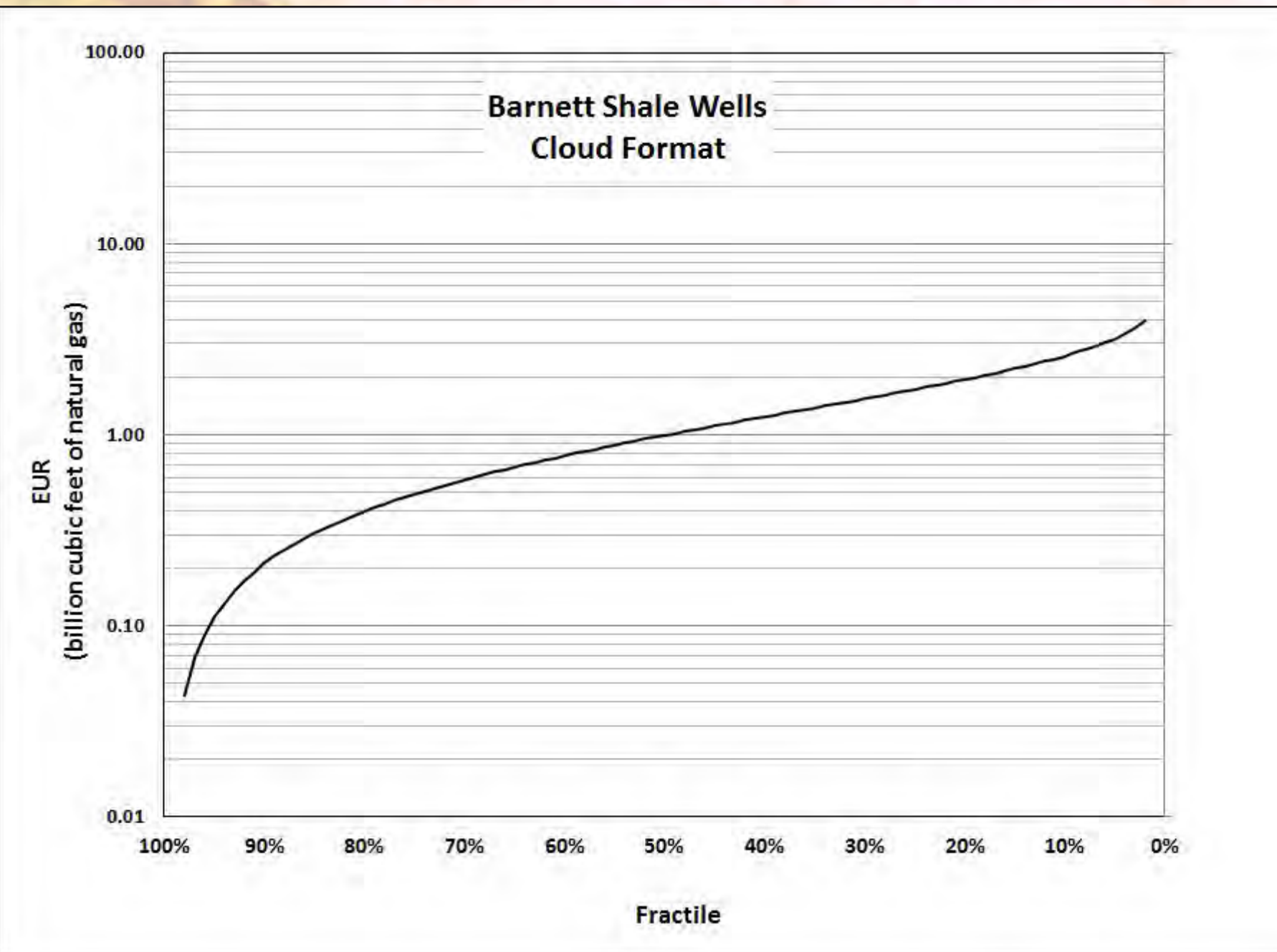

Figure 4. This cloud plot presents the EURs for all Barnett Shale wells drilled through October of 2009 (the same data used for figure 3). The fractiles indicate what percent of the wells have an EUR of at least the indicated amount. Note that the range of EURs is approximately two orders of magnitude.

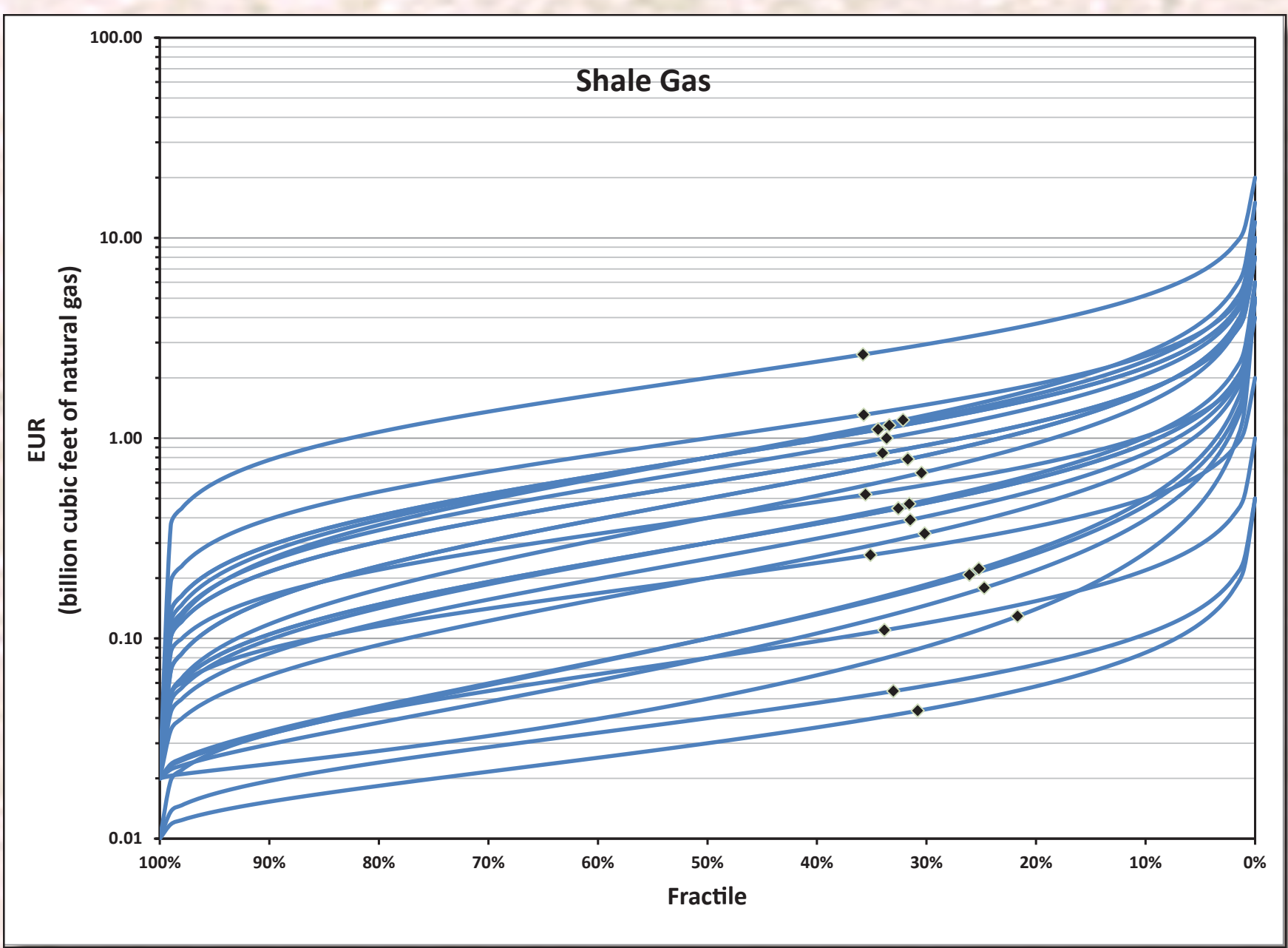## Clouds: Distribution of Distributions

Figure 5. Here, the EUR distributions from 26 USGS assessments of shale-gas resources show the variation from AU to AU (U.S. Geological Survey Oil and Gas Assessment Team, 2012). Each distribution is a truncated shifted lognormal, and thus is a smooth curve. The black diamonds are the means for each distribution. The graph thus presents the "distribution of the distributions." Each distribution is a USGS estimate of the EUR distribution for undrilled productive cells of a particular assessment unit. This graph is termed a "spaghetti plot" which shows how EUR distributions vary for different shale-gas assessment units. The overall area defined by the variation in EUR distributions is termed "the cloud."

Are clouds built from different data sources comparable?

Defining the cloud by using USGS estimates of EUR distributions of undrilled cells gives a good approximation of the range of distributions. Assessments have been conducted over the last decade in a wide variety of reservoirs, using a variety of completion practices, and thus the present sample probably captures much of the range of distributions based on current technology. EUR distributions from decline-curve calculations for previously drilled wells show a consistent cloud pattern, as shown in figures 6 and 7.
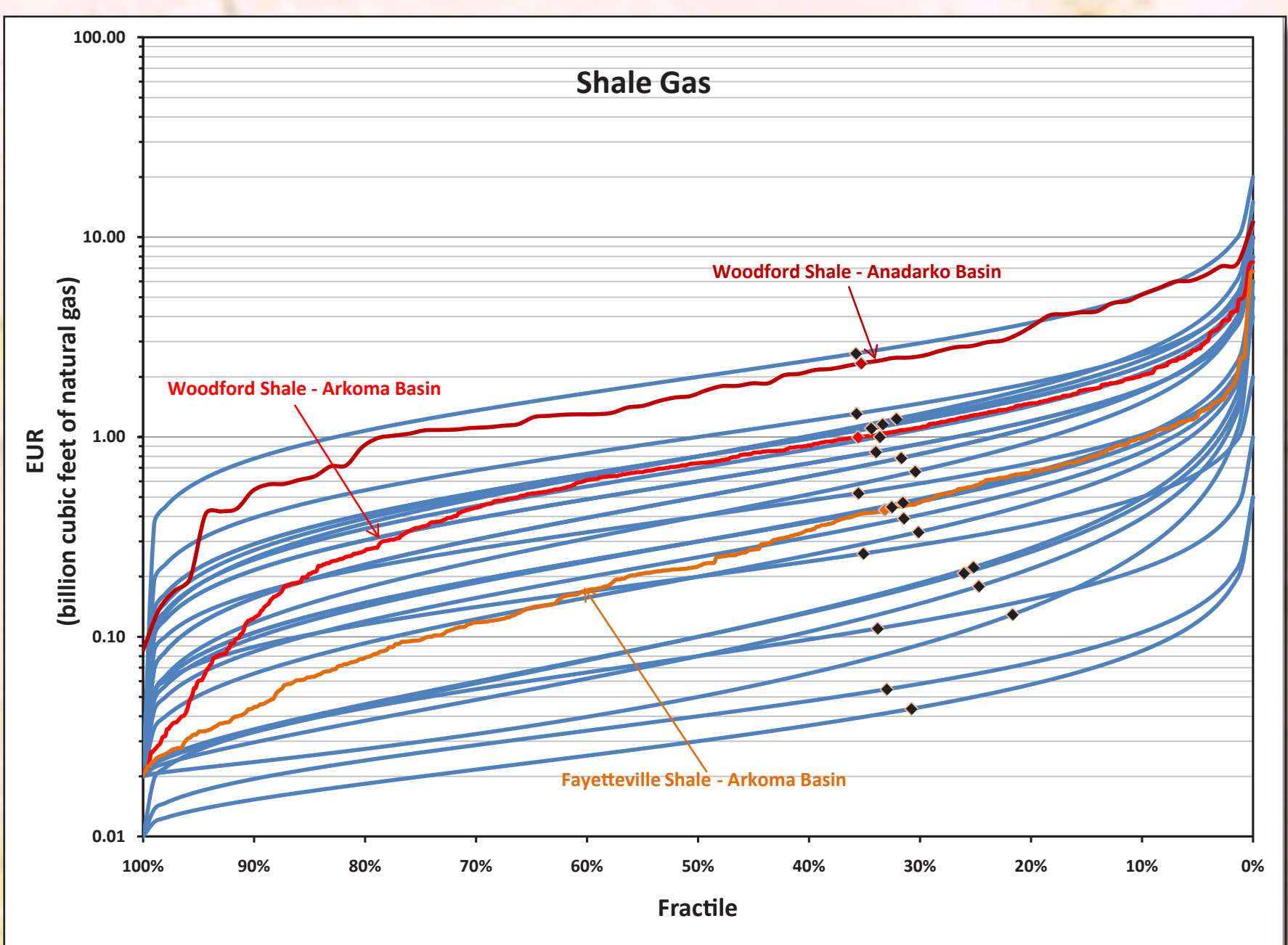

Figure 6. This graph adds the EUR distributions for three recent USGS sets of shale-gas wells, plotted against the cloud shown previously, to put the three distributions in context (Charpentier and Cook, 2010). The three additional curves are not smooth because they are based on actual well data and not on fitted distributions. The curves fall within the range of variability defined in figure 5.
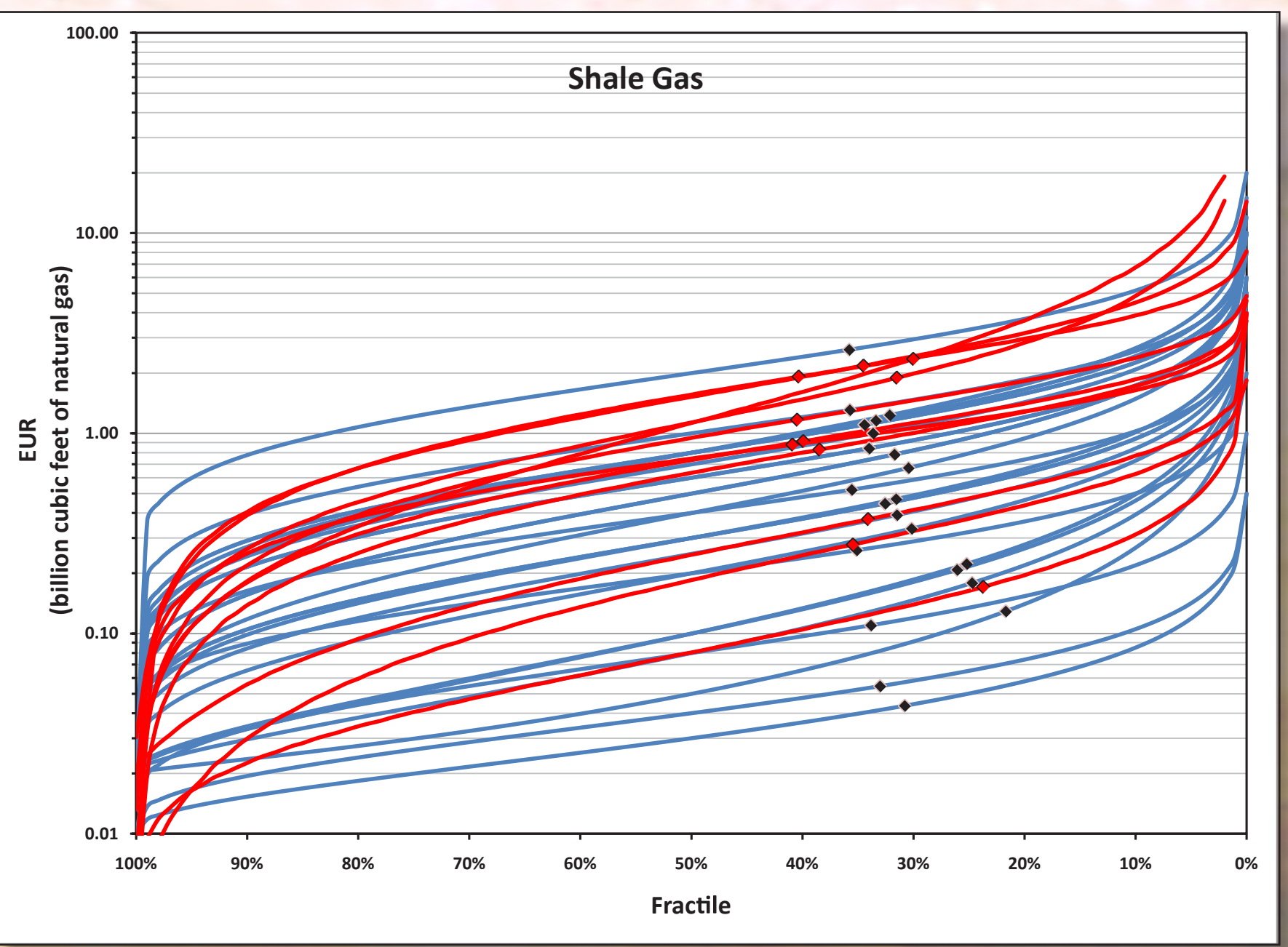

Figure 7. In this graph, the EUR distributions for eleven sets of shale-gas wells are plotted in red against the cloud to put them into context (Charpentier and Cook, 2010). Each of the eleven sets is a subset of the previously drilled wells within an AU. Horizontal and vertical wells are in separate subsets. These red curves are smooth because distributions have been fitted to each set of data. The distributions are of various types, not necessarily lognormal. Again, the data from previously drilled wells give a similar range of variability as from the estimates for undrilled wells.

Variability of Oil and Gas Well Productivities for Continuous (Unconventional) Petroleum Accumulations

By Ronald R. Charpentier and Troy A. Cook
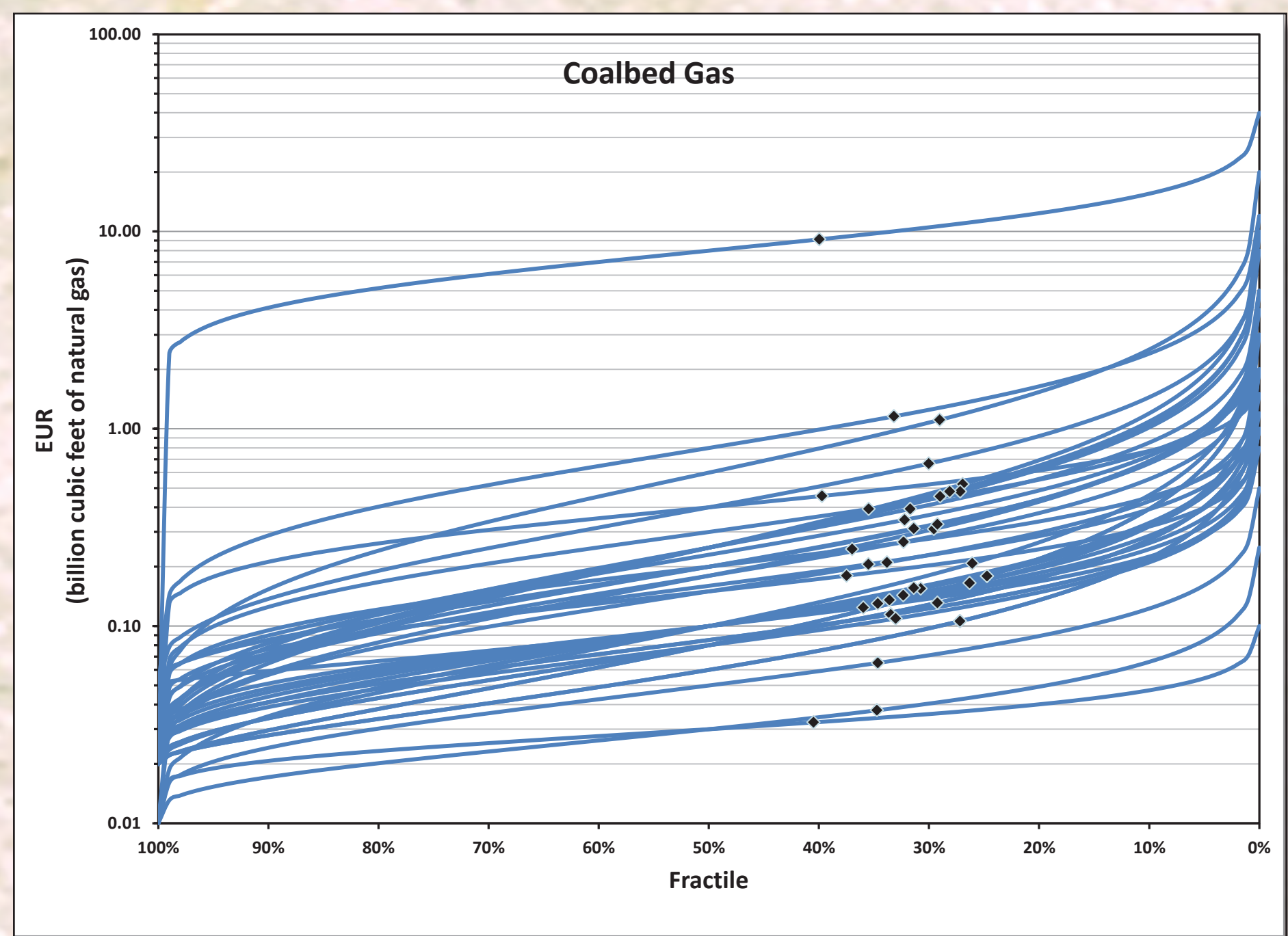2013

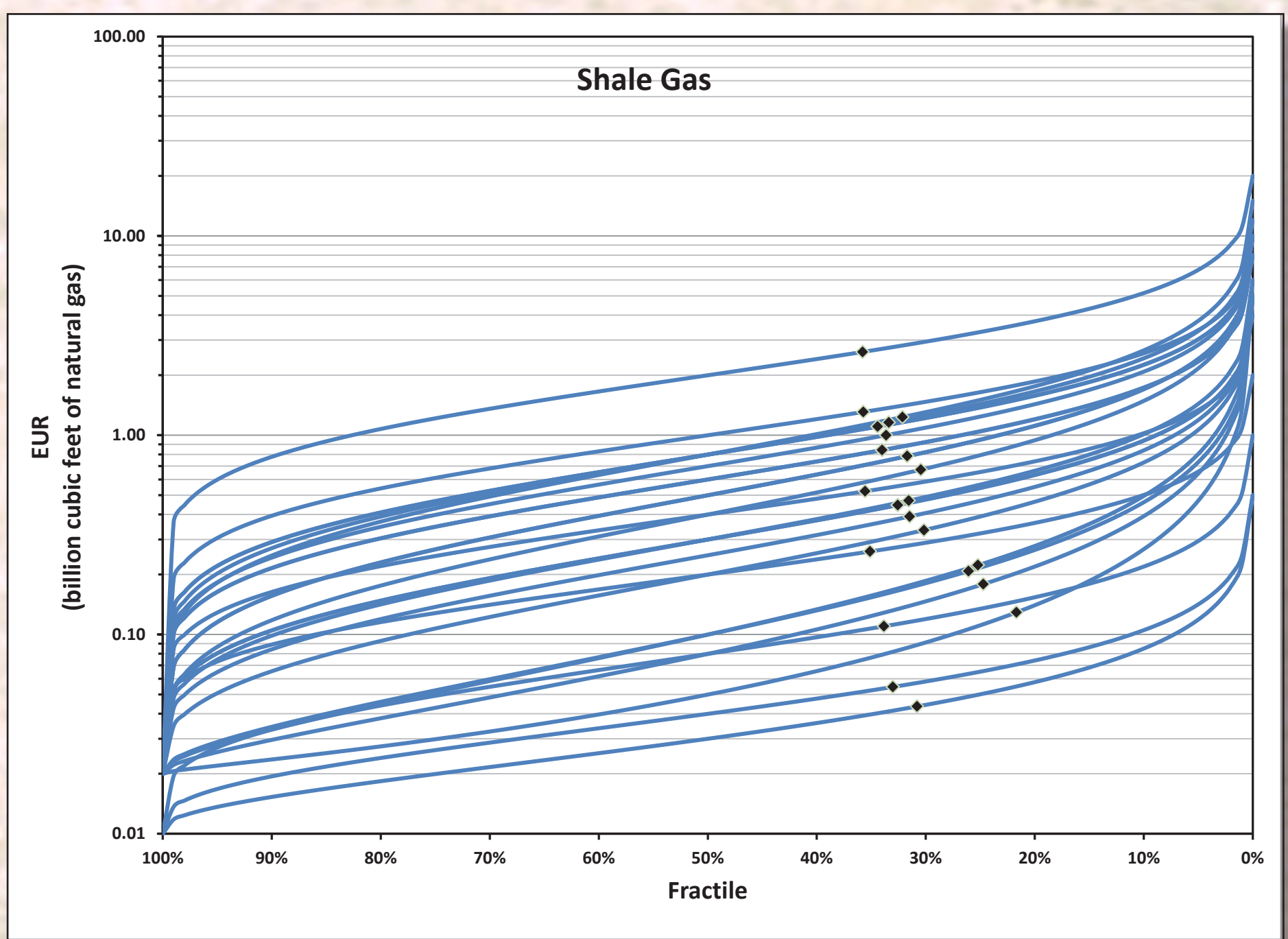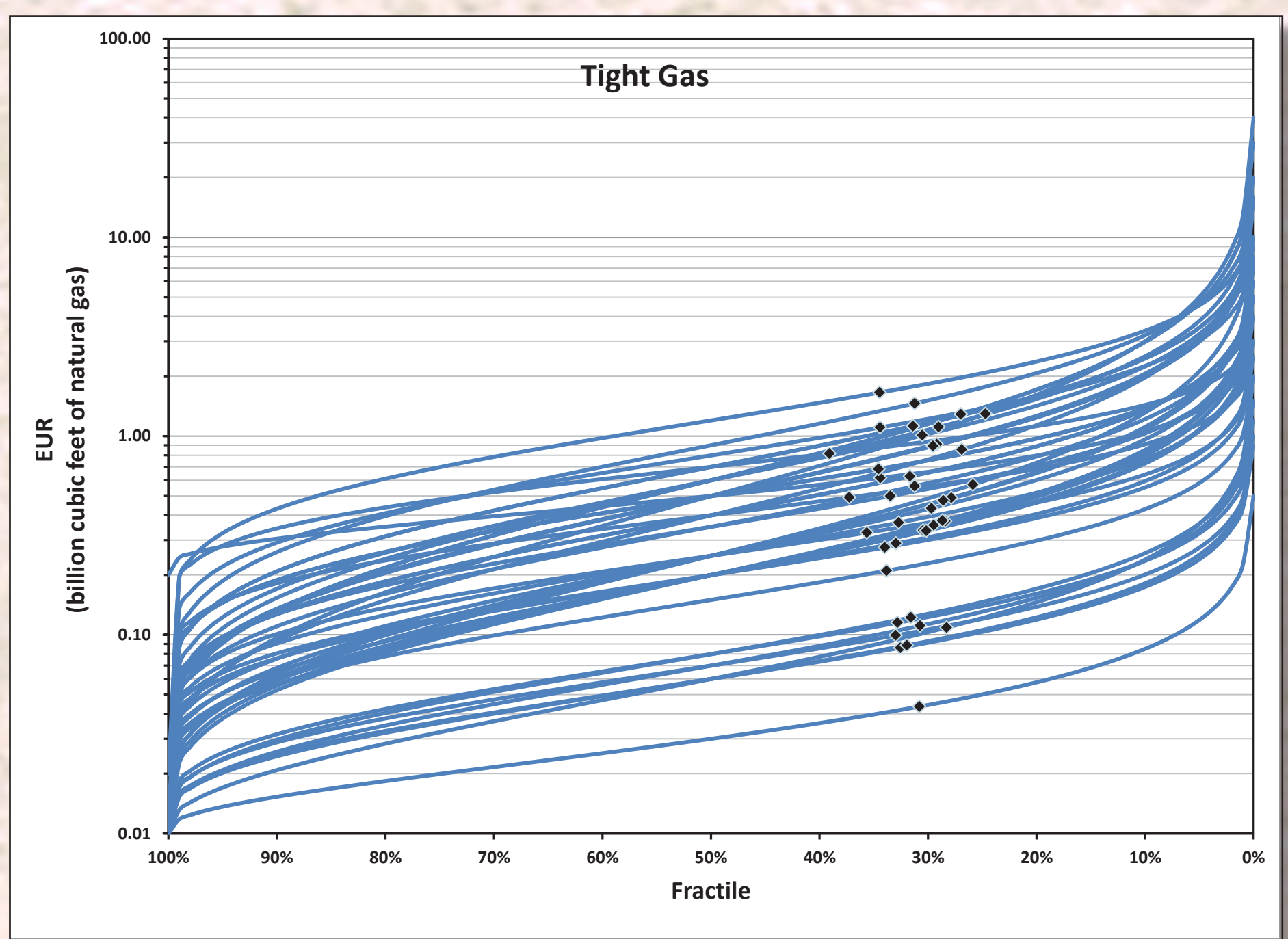## Comparing Clouds

Figure 8.

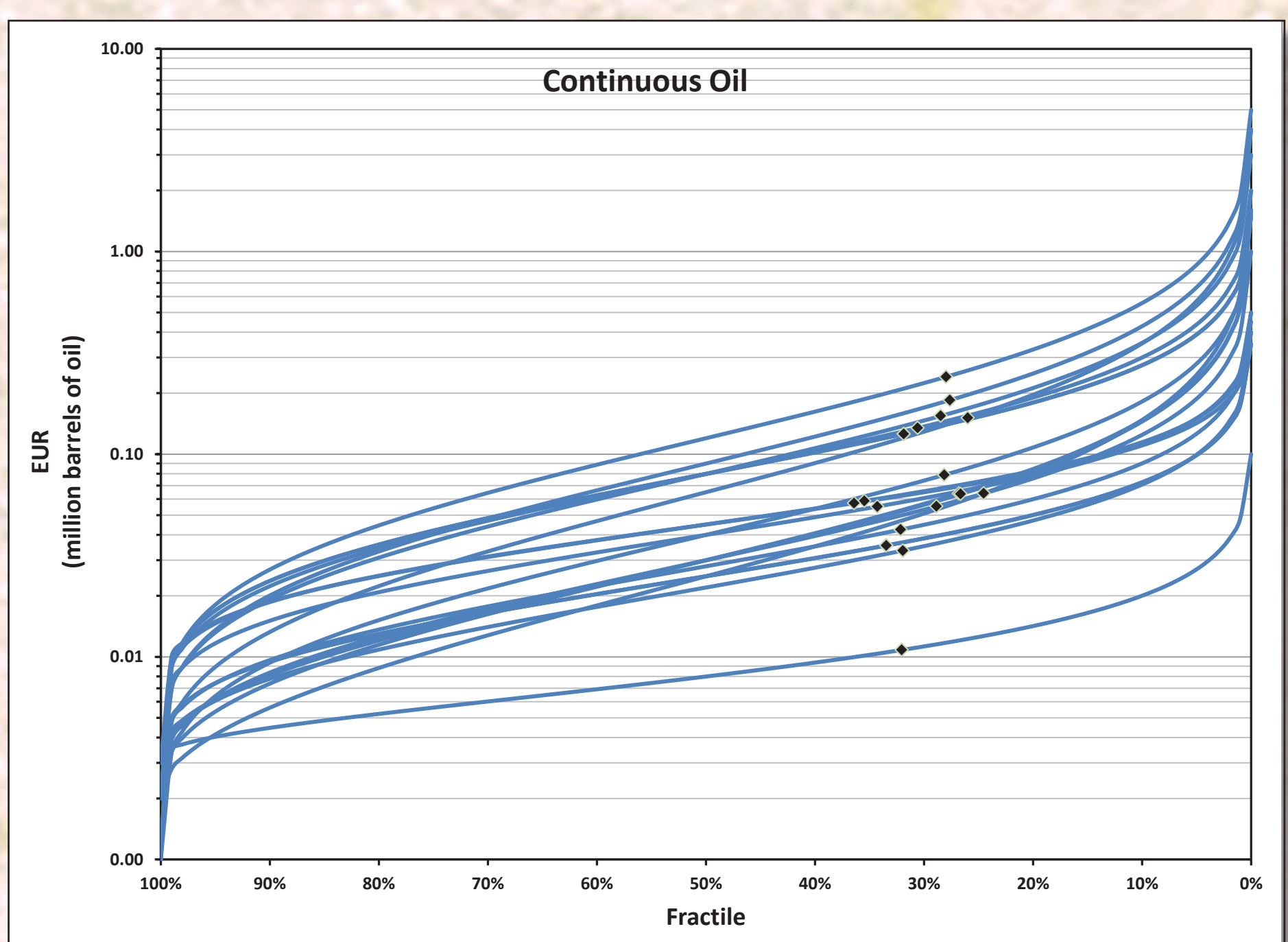

Figure 9.

Figure 10.

Figure 11.

Figures 9–11. The USGS AUs were divided into four categories based on reservoir type and major commodity (oil or gas): coalbed gas, shale gas, other low-permeability gas AUs (referred to as tight gas), and continuous oil AUs. These graphs show the variation among the four groups. Note the large variations between the highest EUR distributions and the lowest, and between the highest means and the lowest. Note also the considerable overlap among the clouds. Especially note the very high outlier distribution for coalbed gas (the Fruitland Fairway Coalbed Gas AU in the San Juan Basin). The black diamonds are the means for each distribution. Data for these graphs are given in U.S. Geological Survey Oil and Gas Assessment Team (2012).
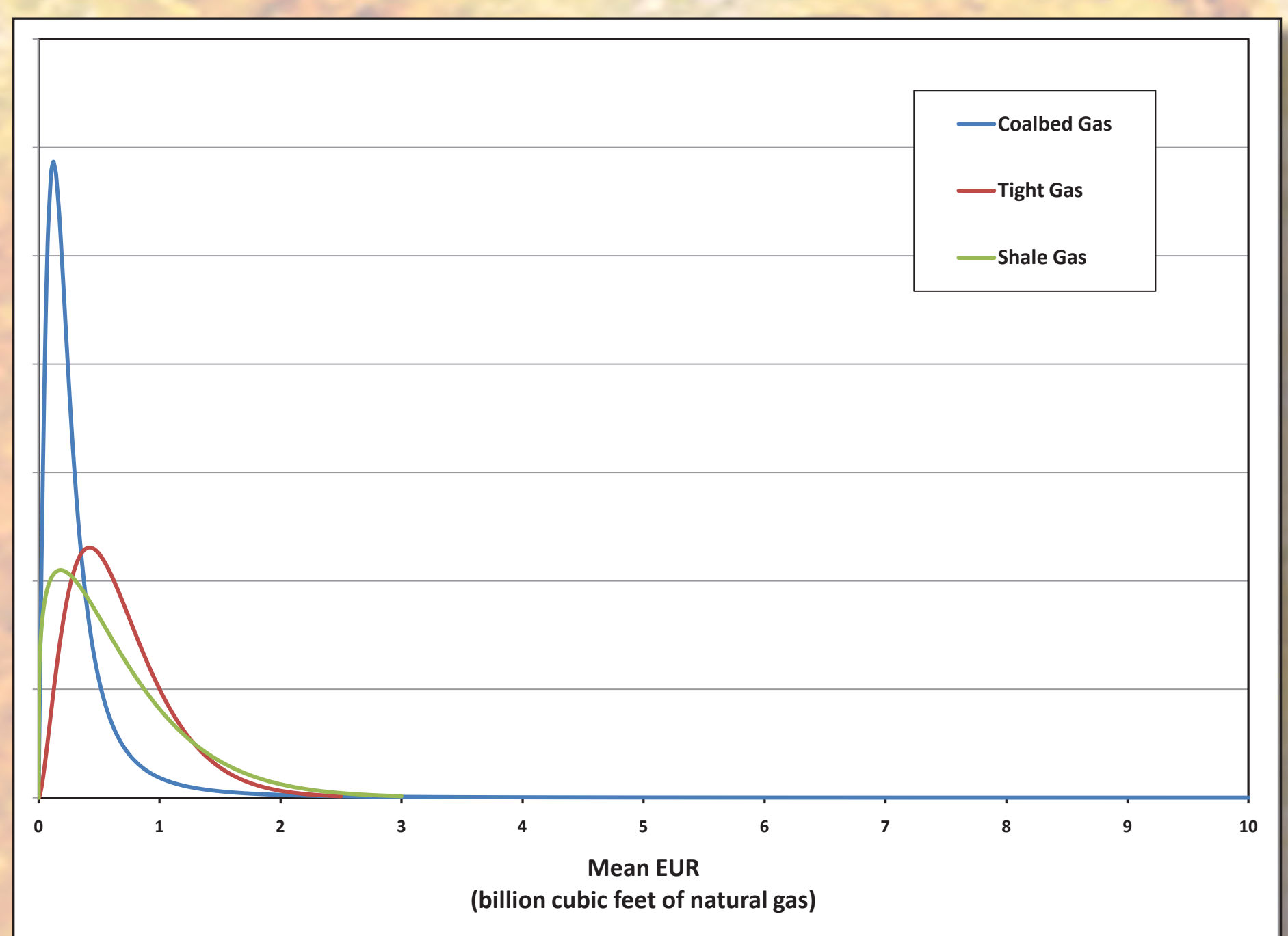
Figure 12.
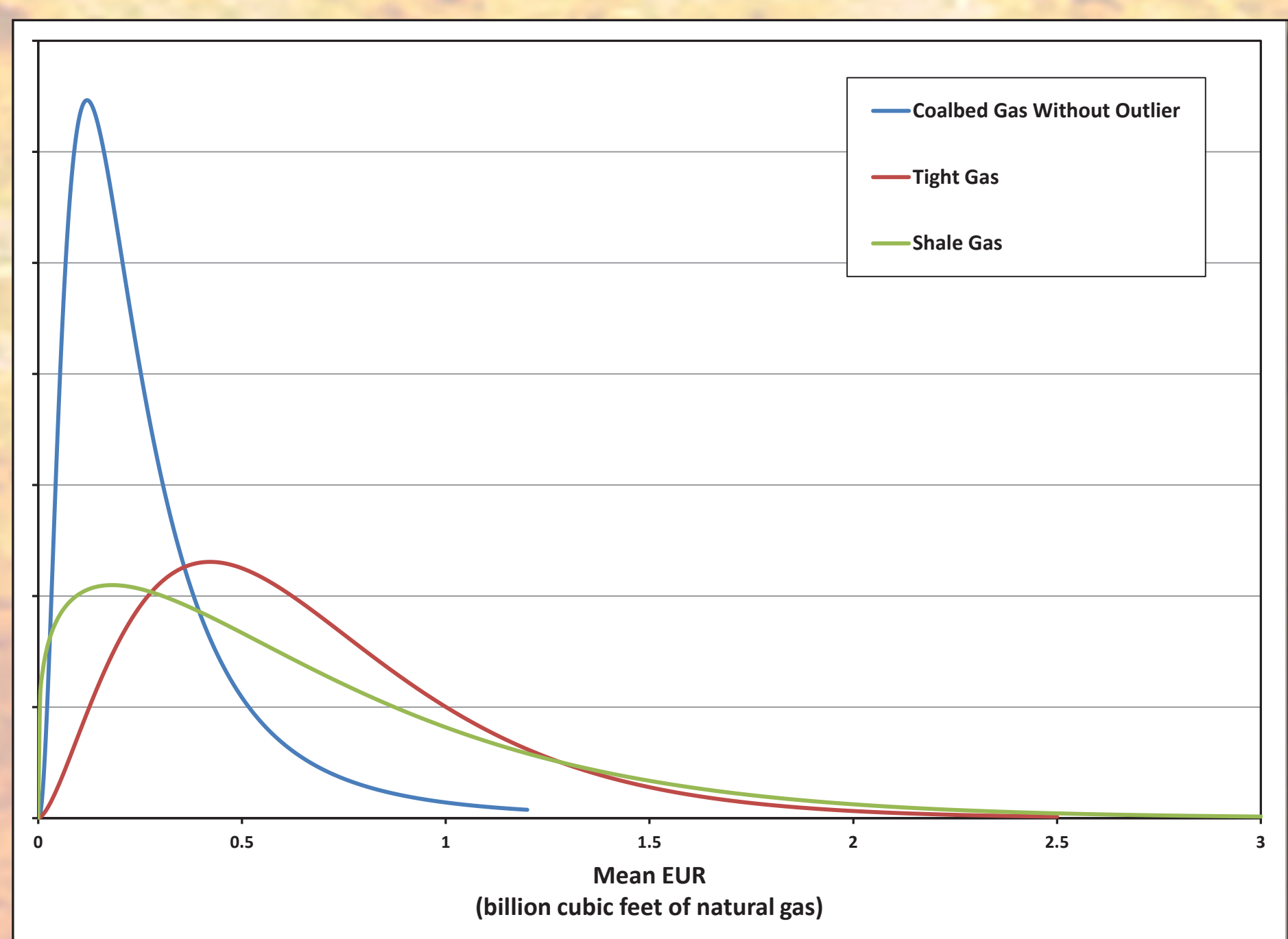
Figure 13.

Figures 12–13. A good way to compare the three clouds for gas resources (coalbed gas, tight gas, and shale gas) is by comparing the distributions of their means. For each set, a best-fit distribution was calculated for the mean EURs. These three distributions are plotted together in figure 12. Note the close similarity between the distribution of means for tight gas and for shale gas, and how coalbed gas generally has much lower means (but a high tail). Eliminating the coalbed-gas outlier changes this little. Figure 13 shows the same distributions for tight gas means and shale gas means, along with a recalculated distribution of coalbed gas means (without the outlier). The recalculated distribution of coalbed gas means is almost the same as the previous one, but without the extreme value. Because all the means from figures 8 through 10 are now less than 3, figure 13 has been rescaled.

Drilling Down Into Assessment Unit Variability
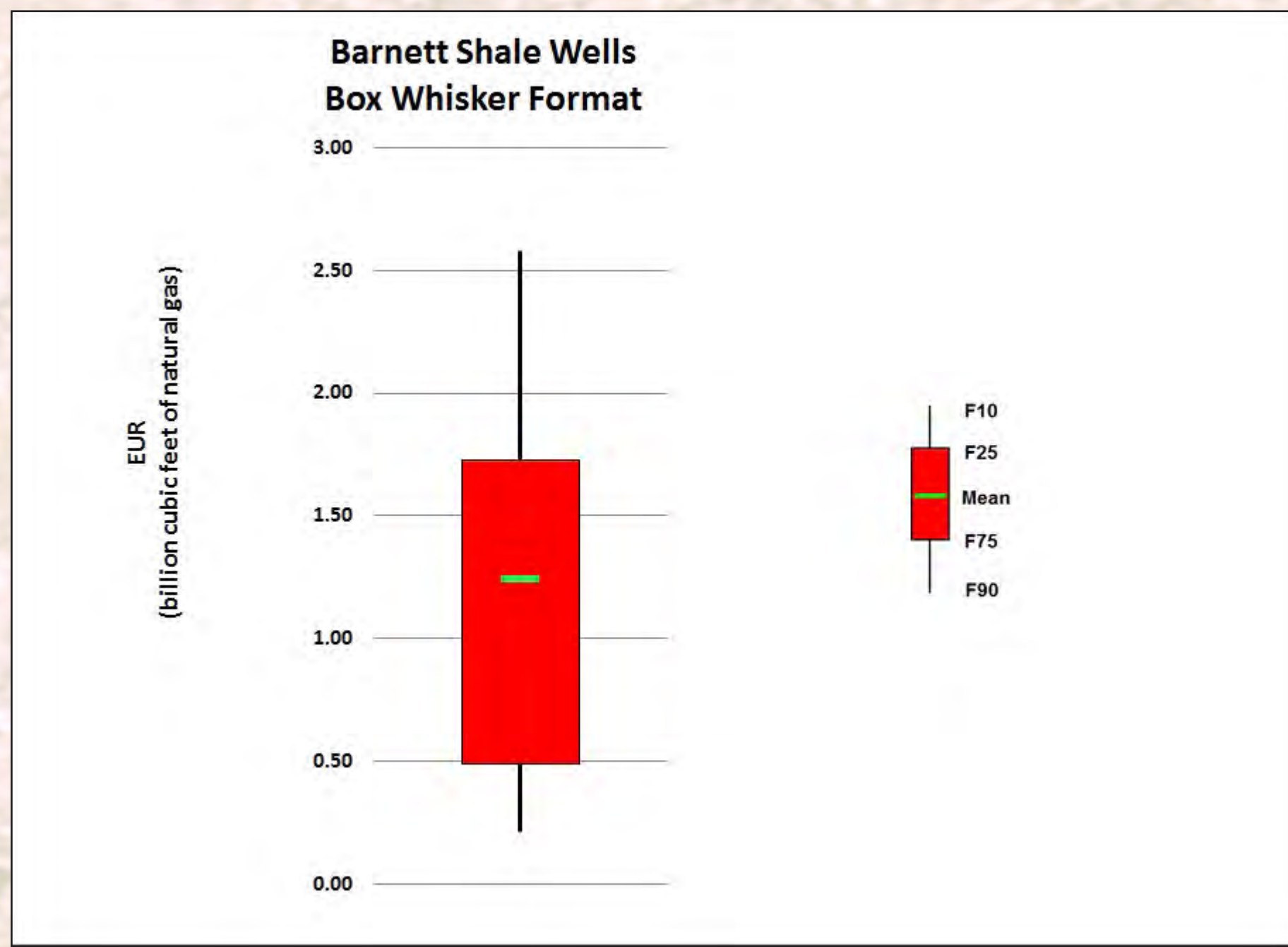
Top-Level Variability

Figure 14. This box-whisker plot presents the EURs for all Barnett Shale wells drilled through October of 2009.
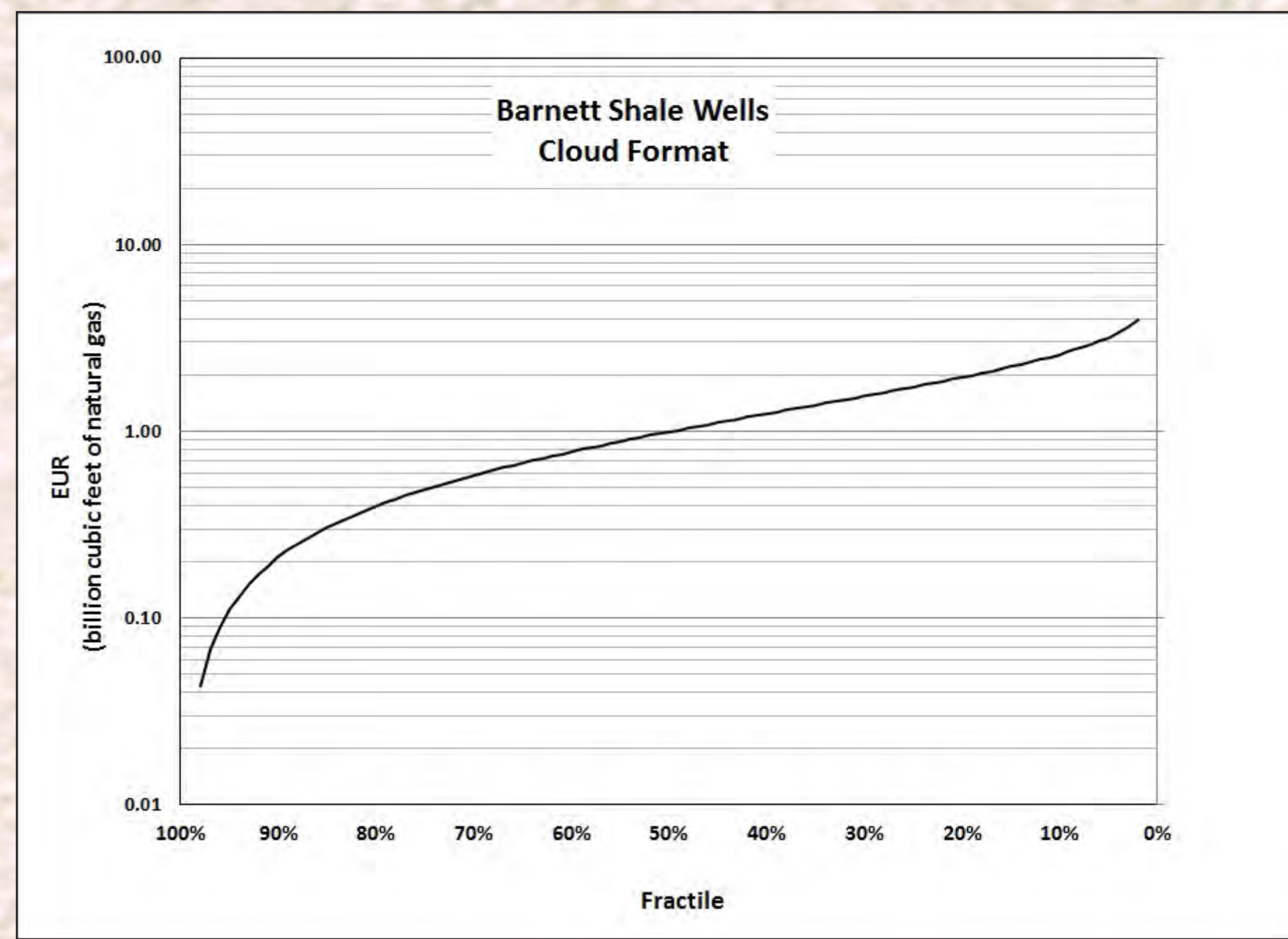

Figure 15. This cloud plot presents the EURs for all Barnett Shale wells drilled through October of 2009 (the same data used for figure 14). The fractiles indicate what percent of the wells have an EUR of at least the indicated amount. Note that the range of EURs is approximately two orders of magnitude.
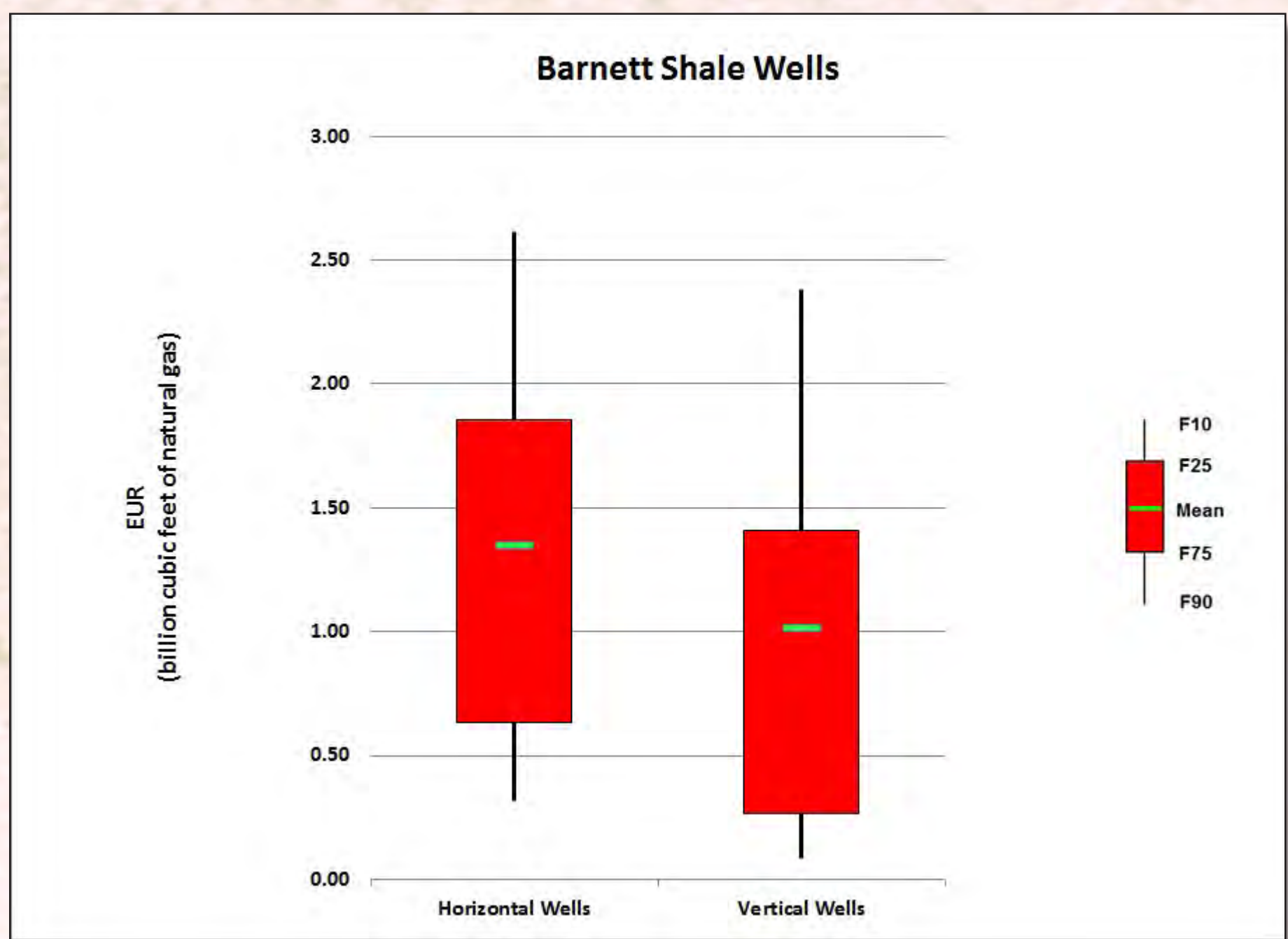
2nd Order Variability

Figure 16. A comparison of EUR between horizontal and vertical Barnett Shale wells.
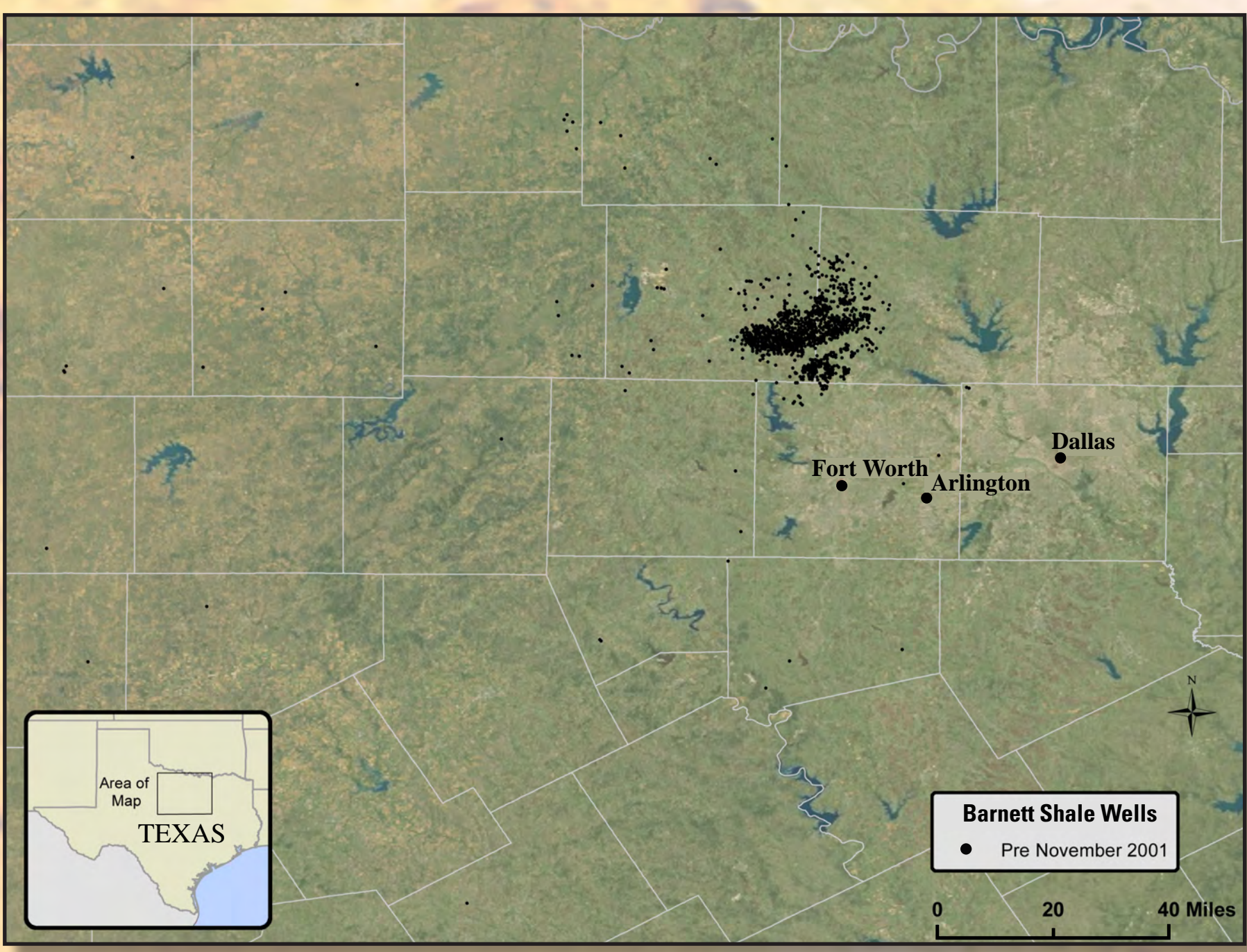

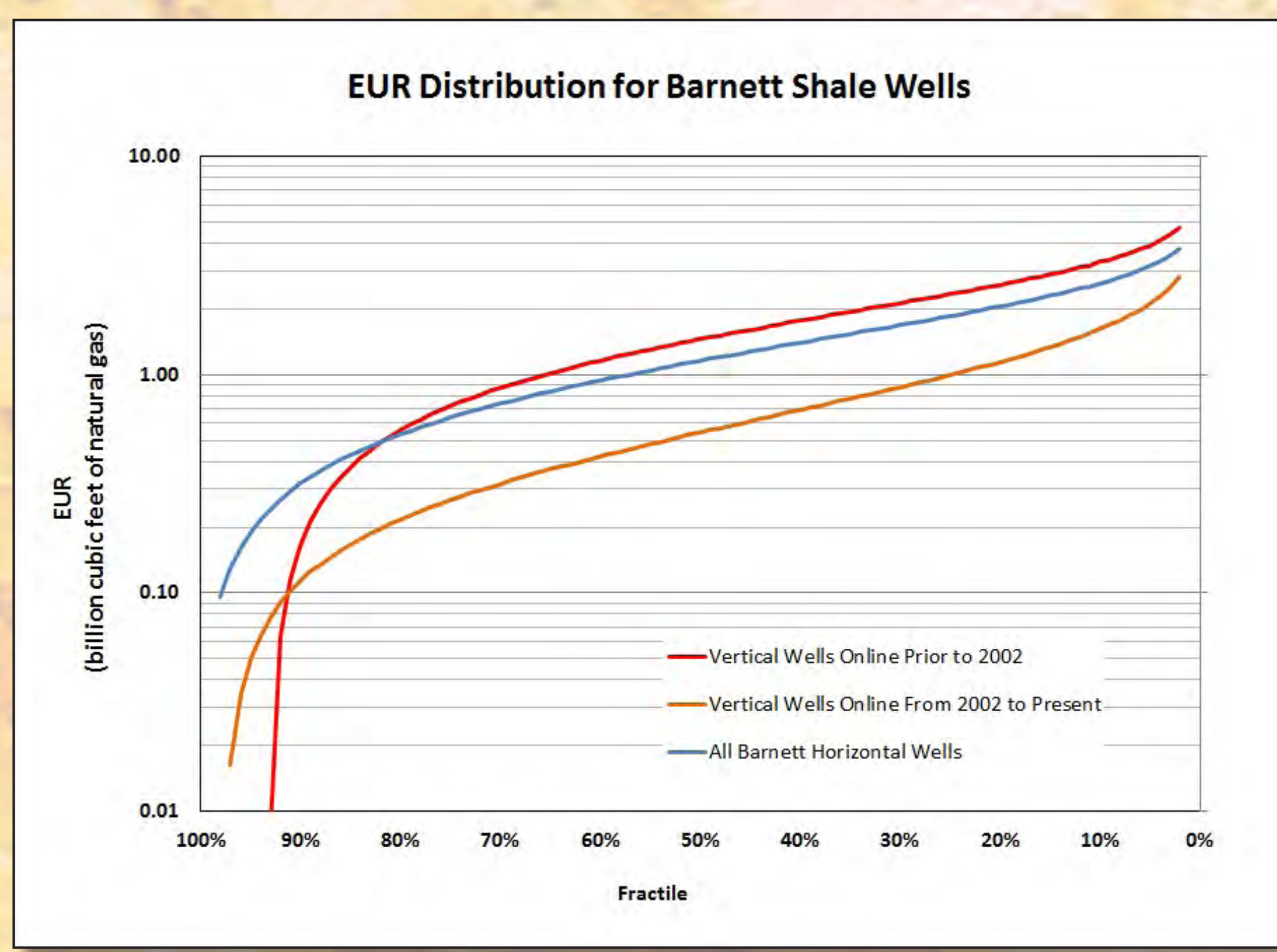Figure 17. All Barnett Shale wells drilled through November 2001

Figure 18. A comparison of Barnett Shale vertical wells drilled before and after January, 2002, to all horizontal wells. Of note is the major change in distribution of EUR when a majority of vertical wells were drilled outside of the original sweet spot.
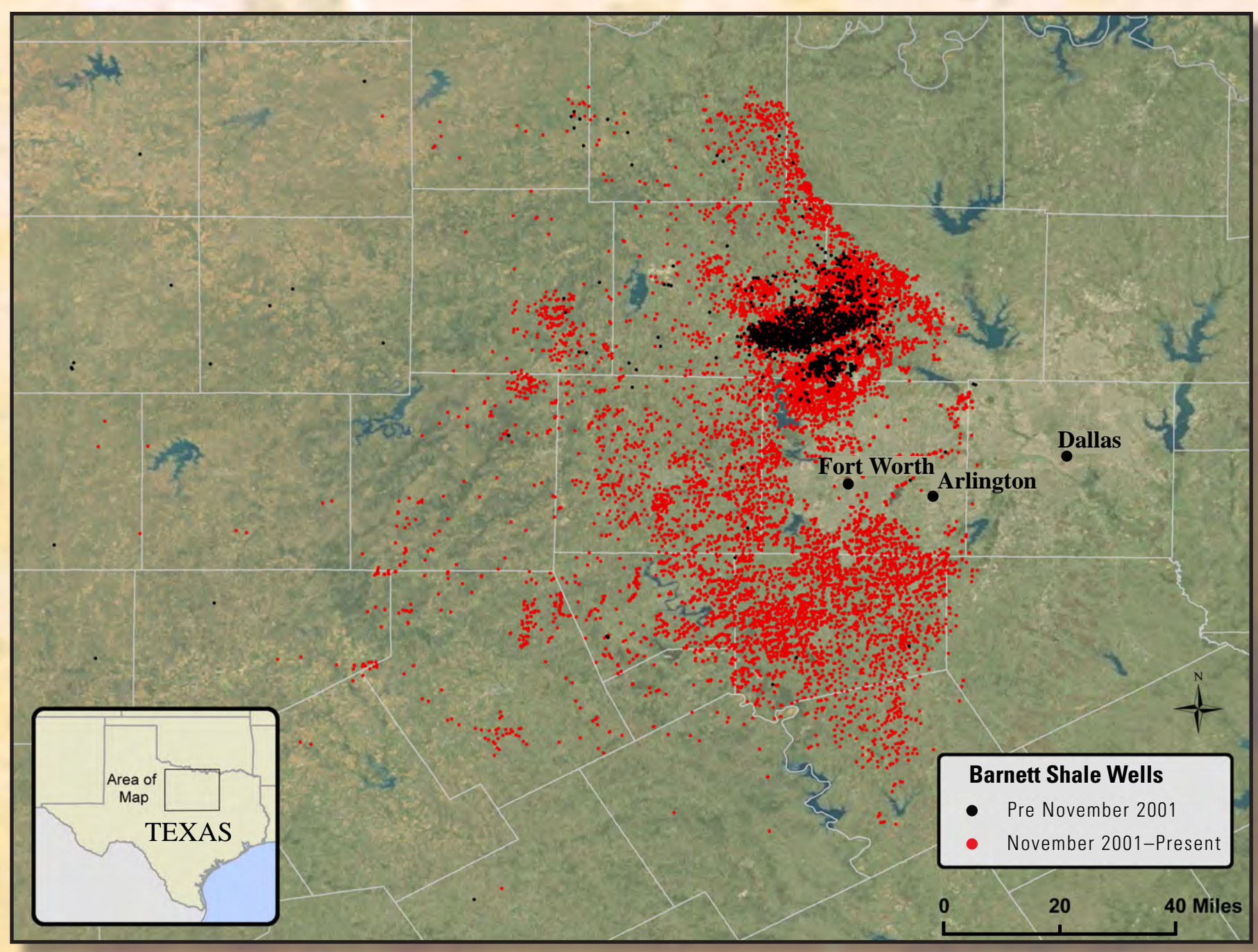

Figure 19. All Barnett Shale wells drilled through November 2009.

Suggested citation:
Charpentier, R.R., and Cook, T.A., 2013, Variability of oil and gas well productivities for continuous (unconventional) petroleum accumulations: U.S. Geological Survey Open-File Report 2013–1001, 3 sheets.

Variability of Oil and Gas Well Productivities for Continuous (Unconventional) Petroleum Accumulations

By Ronald R. Charpentier and Troy A. Cook

2013

Variability Comes from Several Factors

V E R T I C A L W E L L S
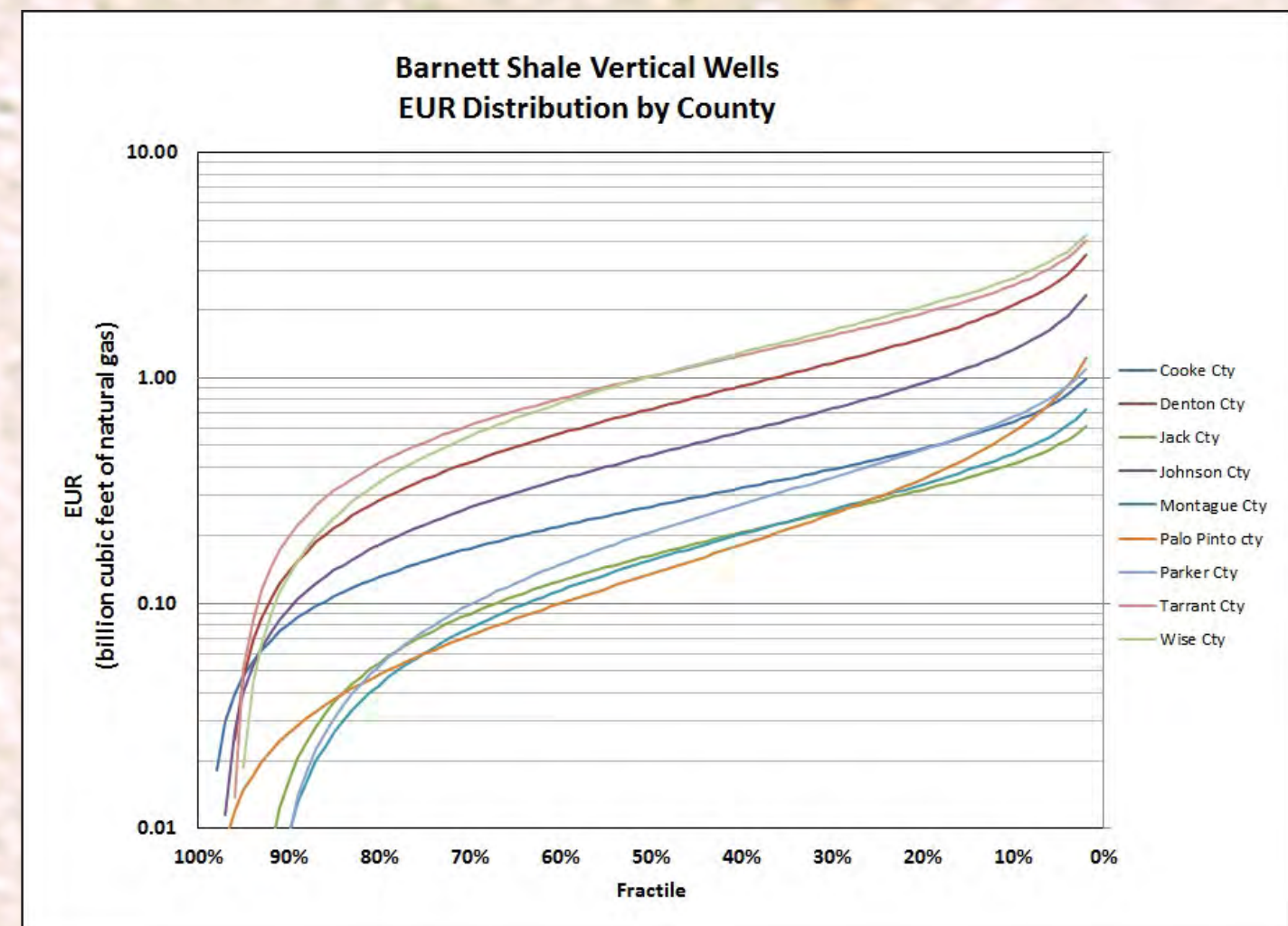
Spatial Changes in EUR

Figure 20. This plot of EUR distributions by county for Barnett Shale vertical wells shows the variability in well productivity from county to county. Compare with the comparable graph for horizontal wells (figure 21).
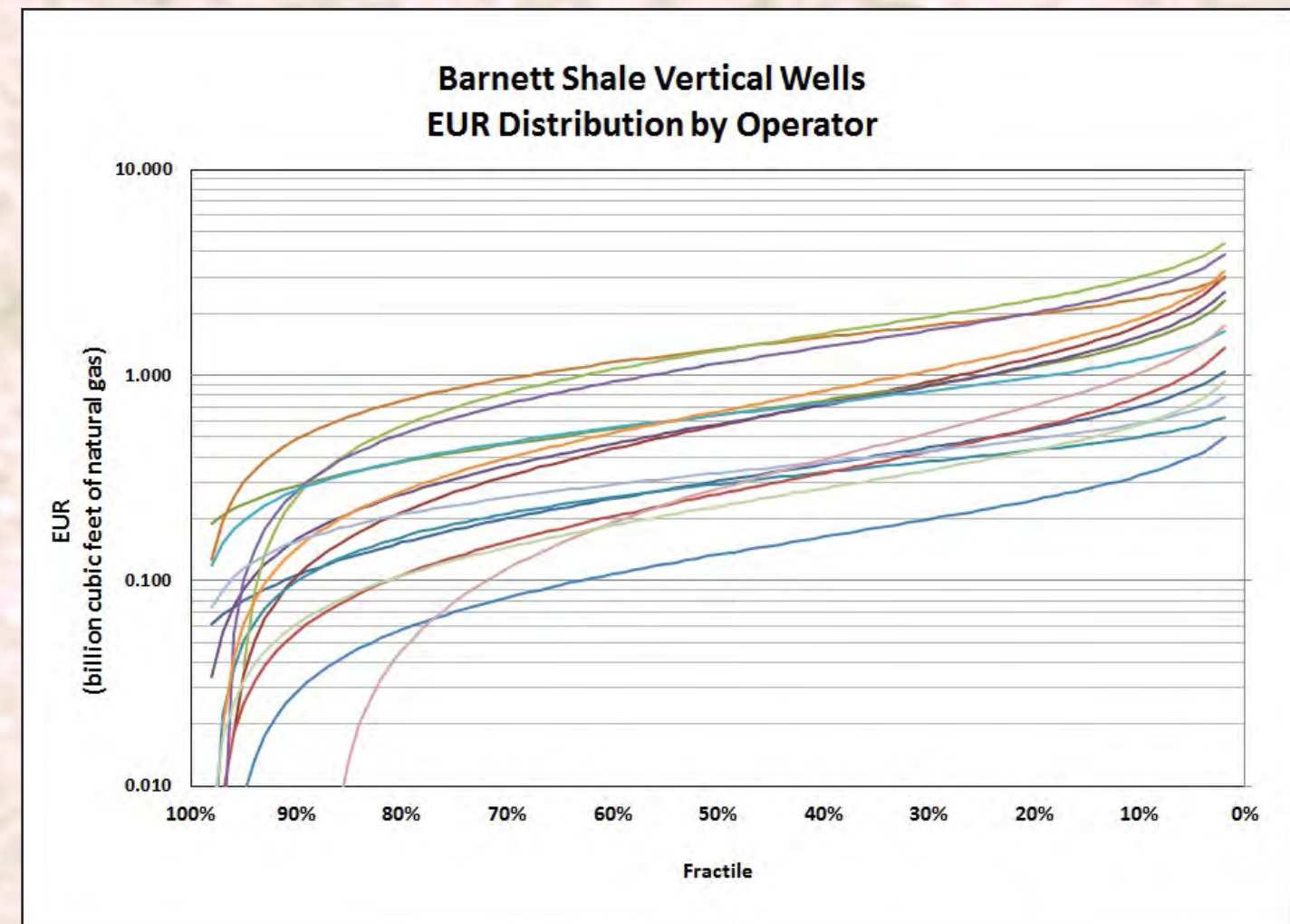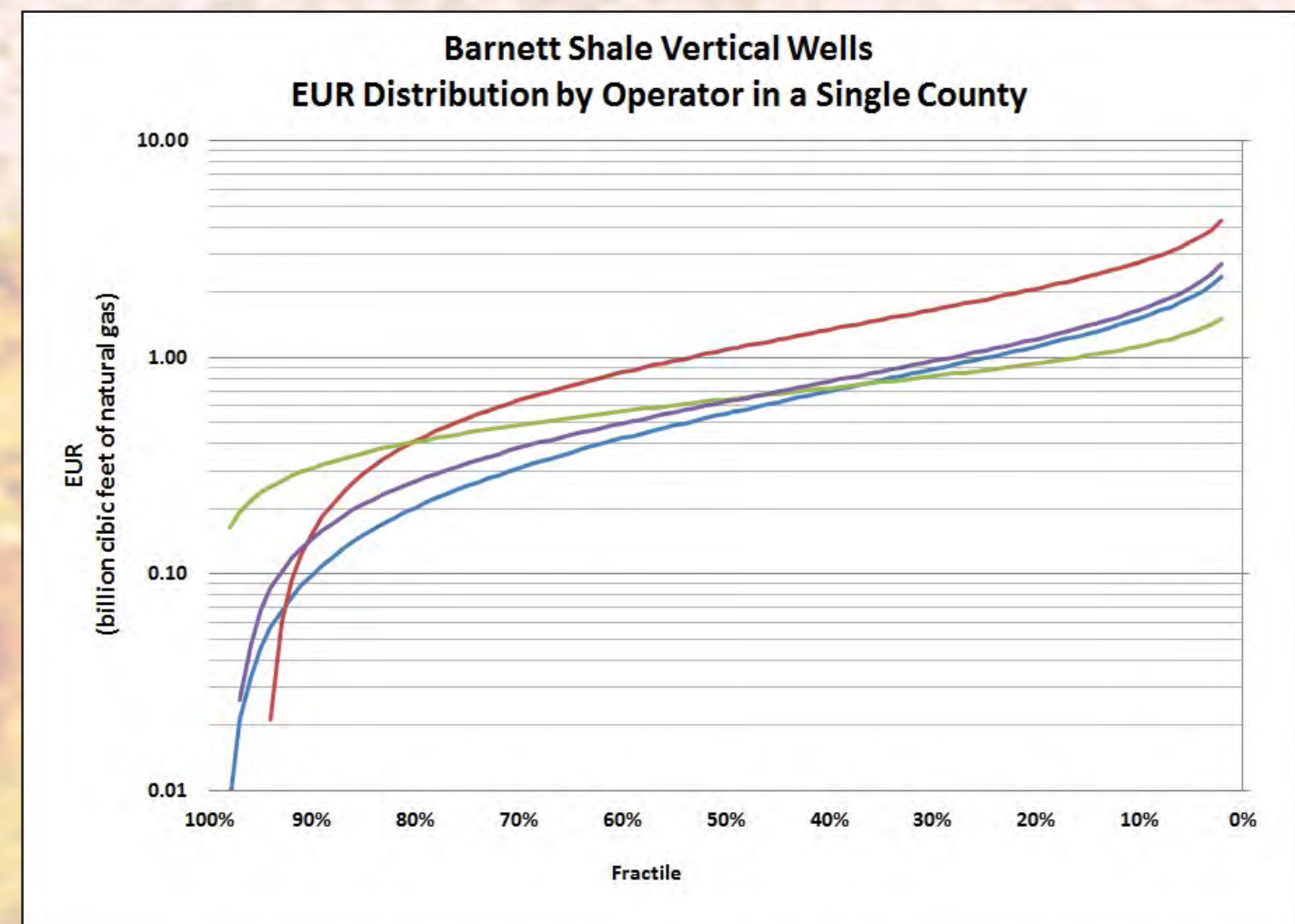
Figure 21. This plot of EUR distributions by county for Barnett Shale horizontal wells shows the variability in well productivity from county to county. Compare with the comparable graph for vertical wells (figure 20).

Figure 22. This plot of EUR distributions by operator for Barnett Shale vertical wells shows the variability in well productivity from operator to operator. Compare with the comparable graph for horizontal wells (figure 23).

Figure 23. This plot of EUR distributions by operator for Barnett Shale horizontal wells shows the variability in well productivity from operator to operator. Compare with the comparable graph for vertical wells (figure 22).

Figure 24. This plot of EUR distributions by operator for Barnett Shale vertical wells for a single county shows the variability in well productivity from operator to operator. Compare with the comparable graph for horizontal wells (figure 25).
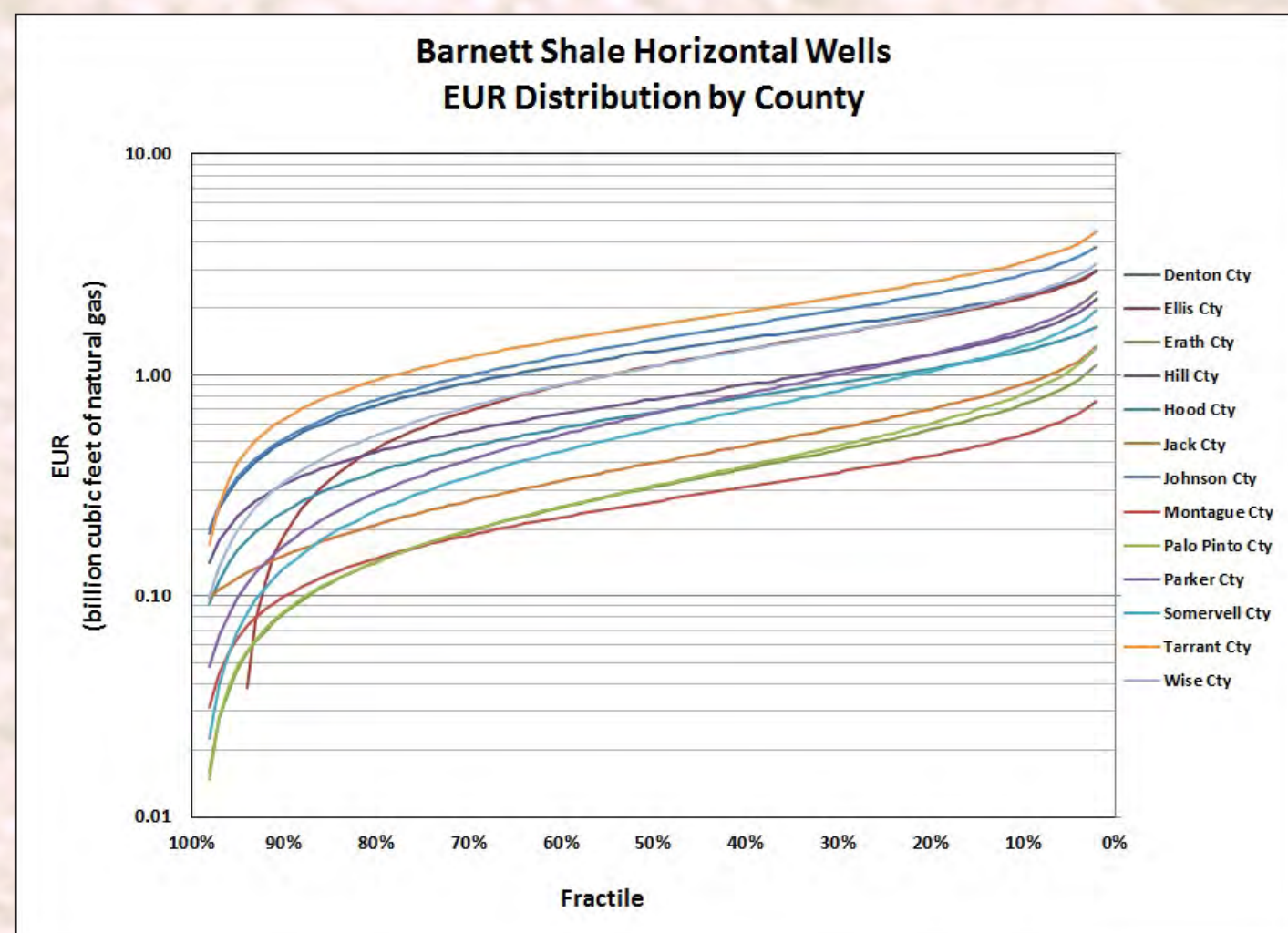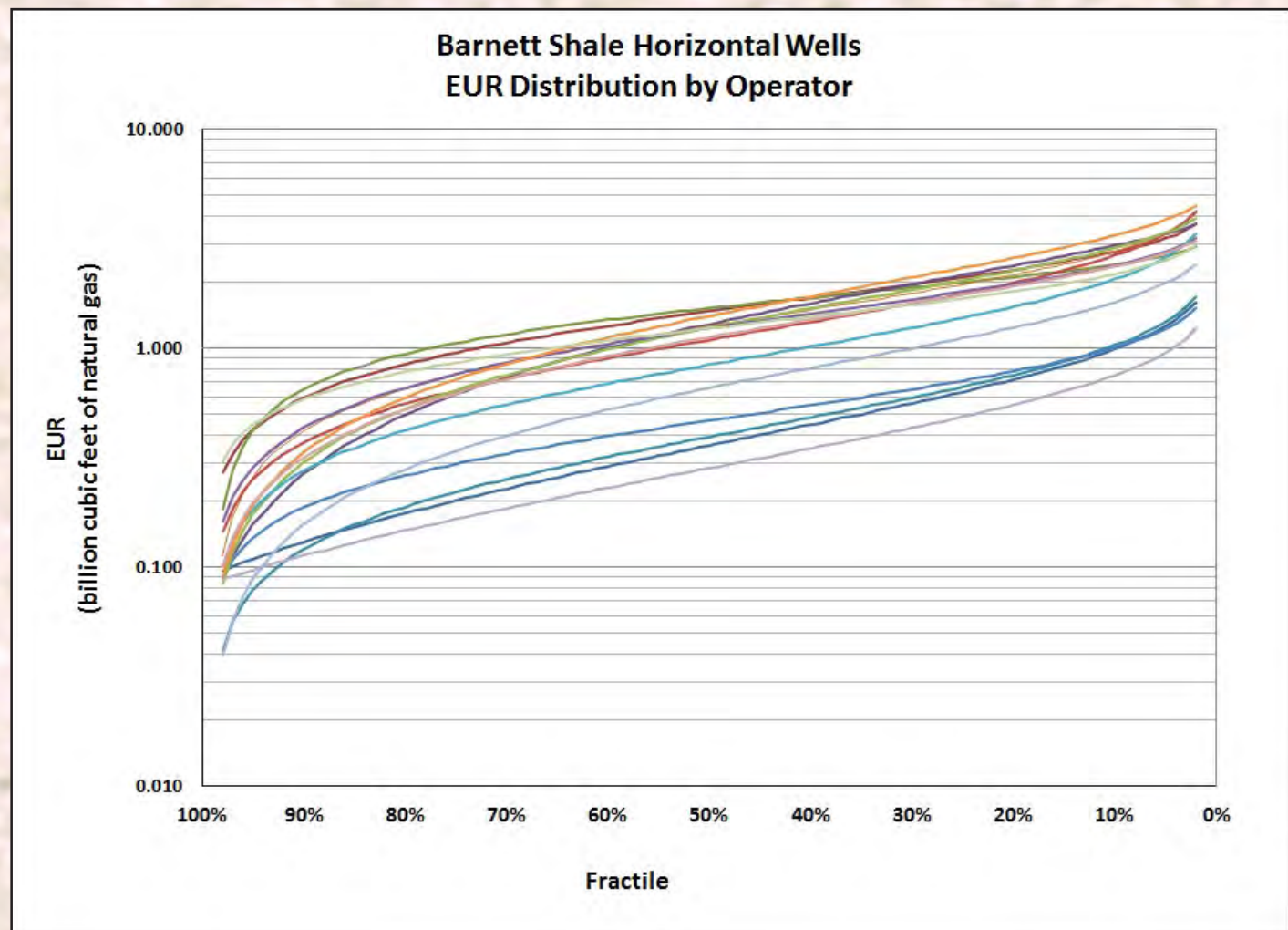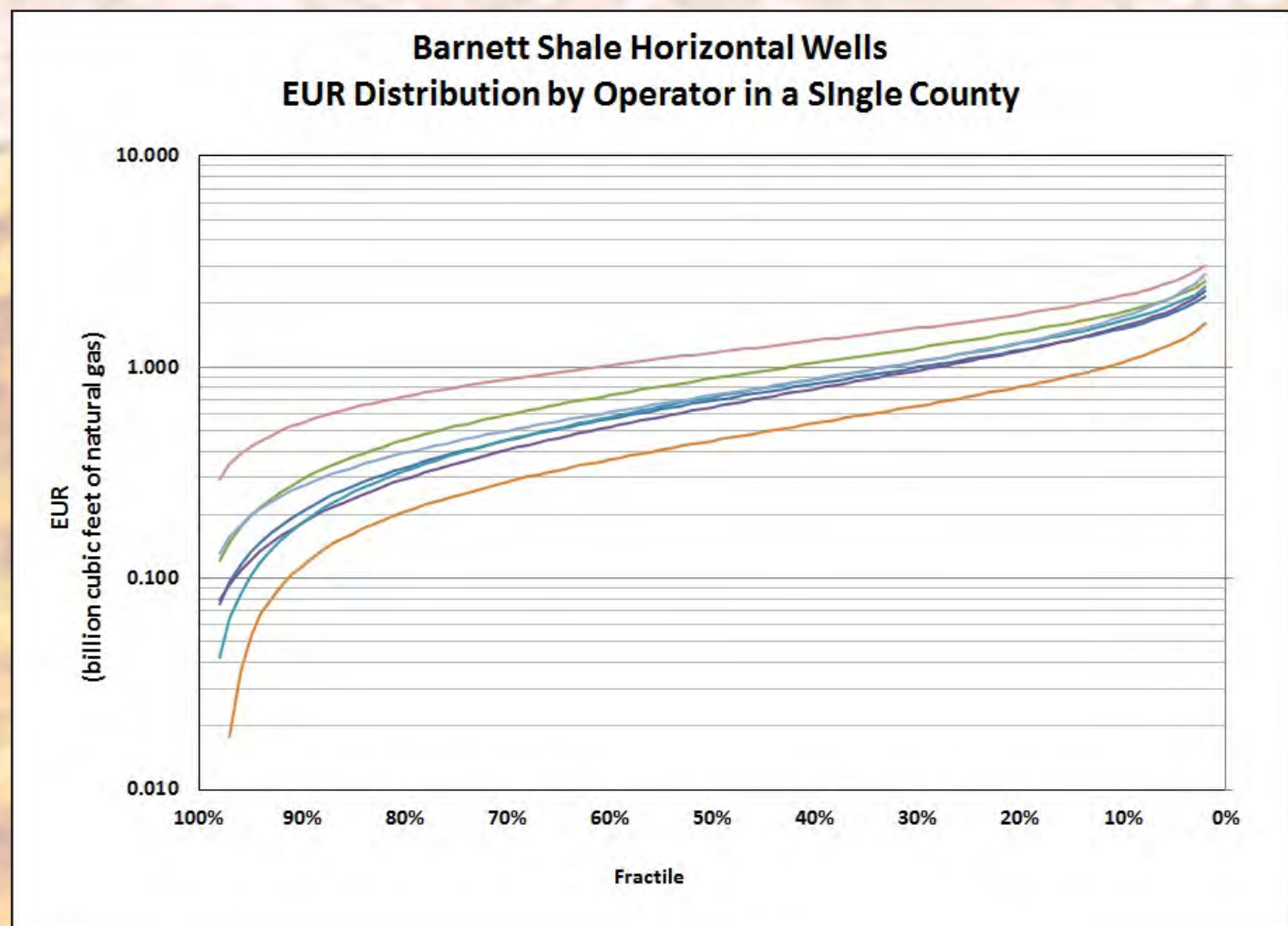
Figure 25. This plot of EUR distributions by operator for Barnett Shale horizontal wells for a single county shows the variability in well productivity from operator to operator. Compare with the comparable graph for vertical wells (figure 24).
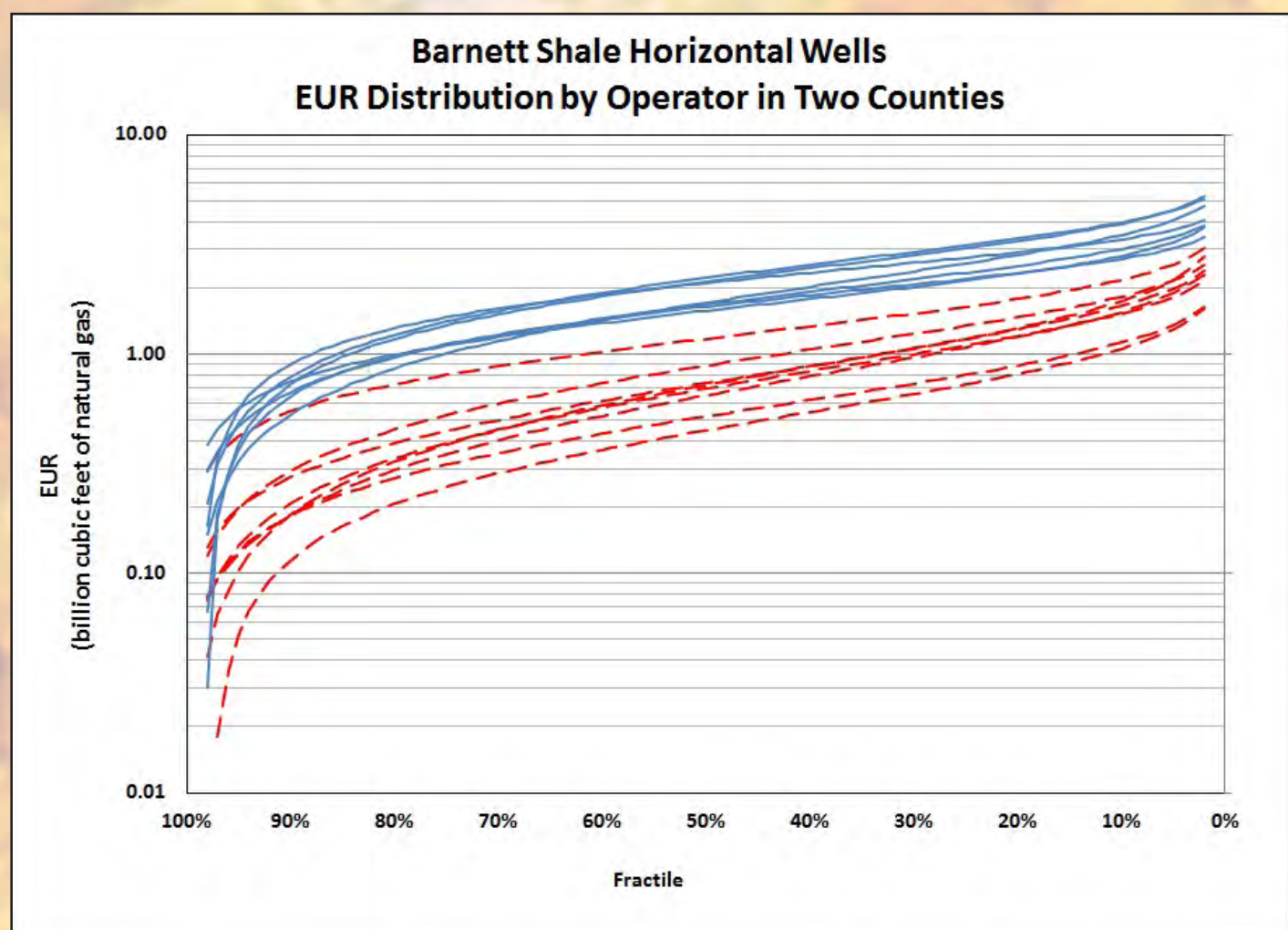
Figure 26. This plot of EUR distributions by operator for Barnett Shale horizontal wells for two counties shows that the variability in well productivity in this case is greater from county to county than from operator to operator. Operators are represented more than once in this figure if they produced wells in both counties, however a majority of the operators are the same in the two counties. Solid blue lines are EUR distributions for the first county; dashed red lines are EUR distributions for the second county.

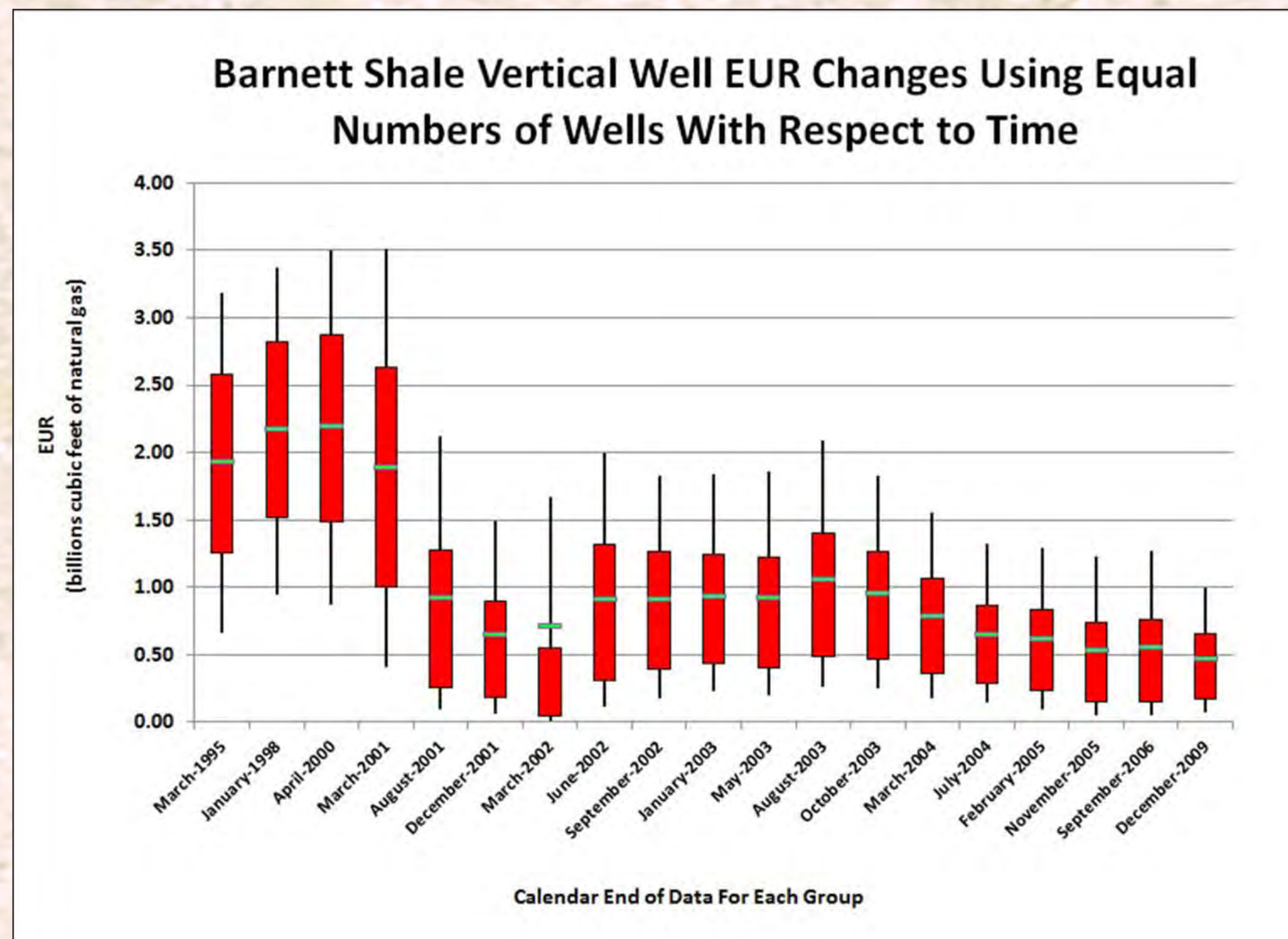**H O R I Z O N T A L W E L L S**

Changes in EUR with Time

Figure 27. Changes with respect to time in EUR distributions for Barnett Shale vertical wells. Each box-whisker plot is based on a group of approximately 200 wells.
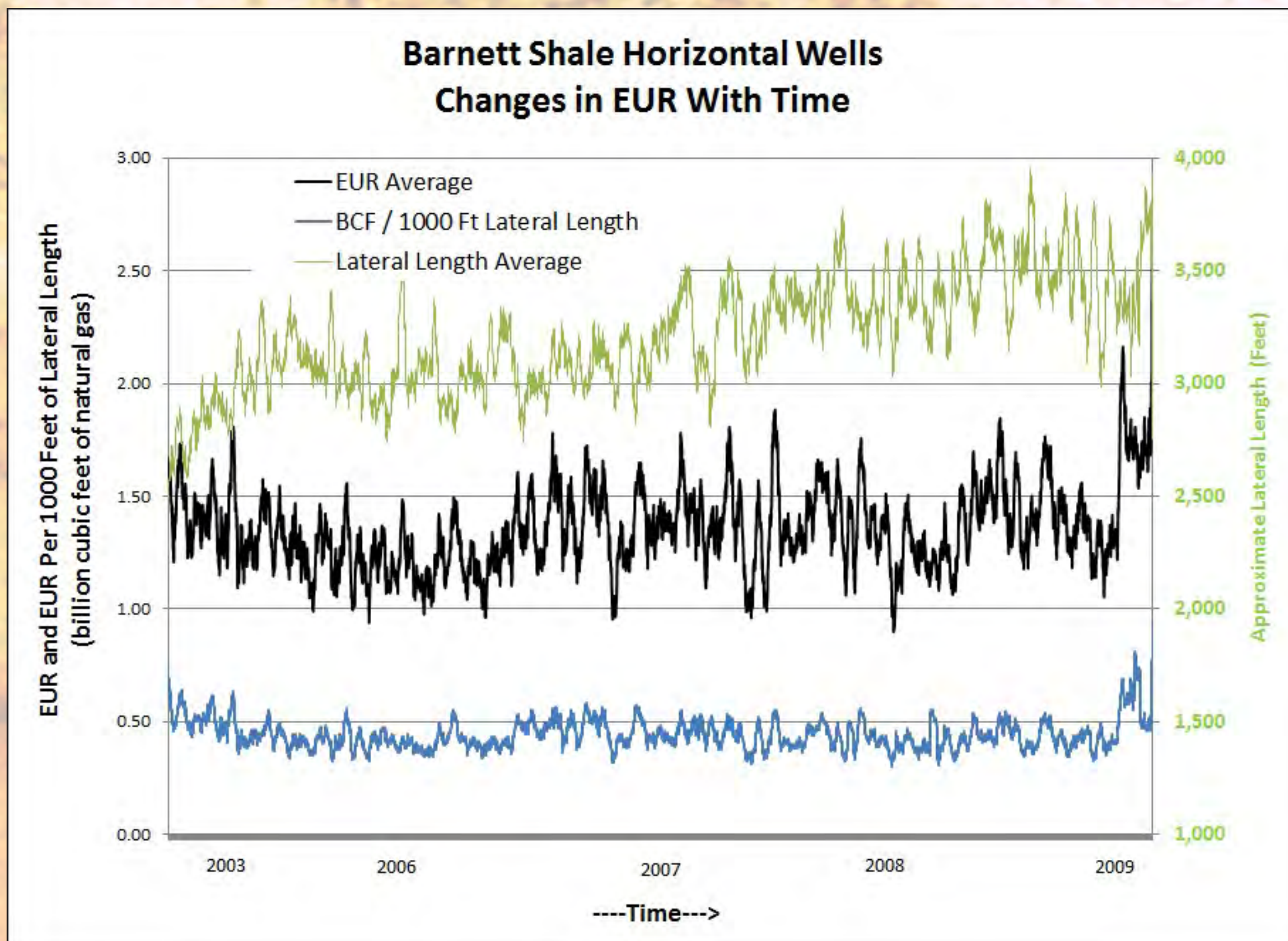

Figure 28. Changes with respect to time in average EUR for Barnett Shale horizontal wells, in average EUR per 1000 feet of lateral length, and in average lateral length. Note the trend of relatively stable productivity per 1000 feet of lateral length over more than 9000 horizontal wells in at least 13 different counties. Values for each line have been smoothed by a 50-well moving average.

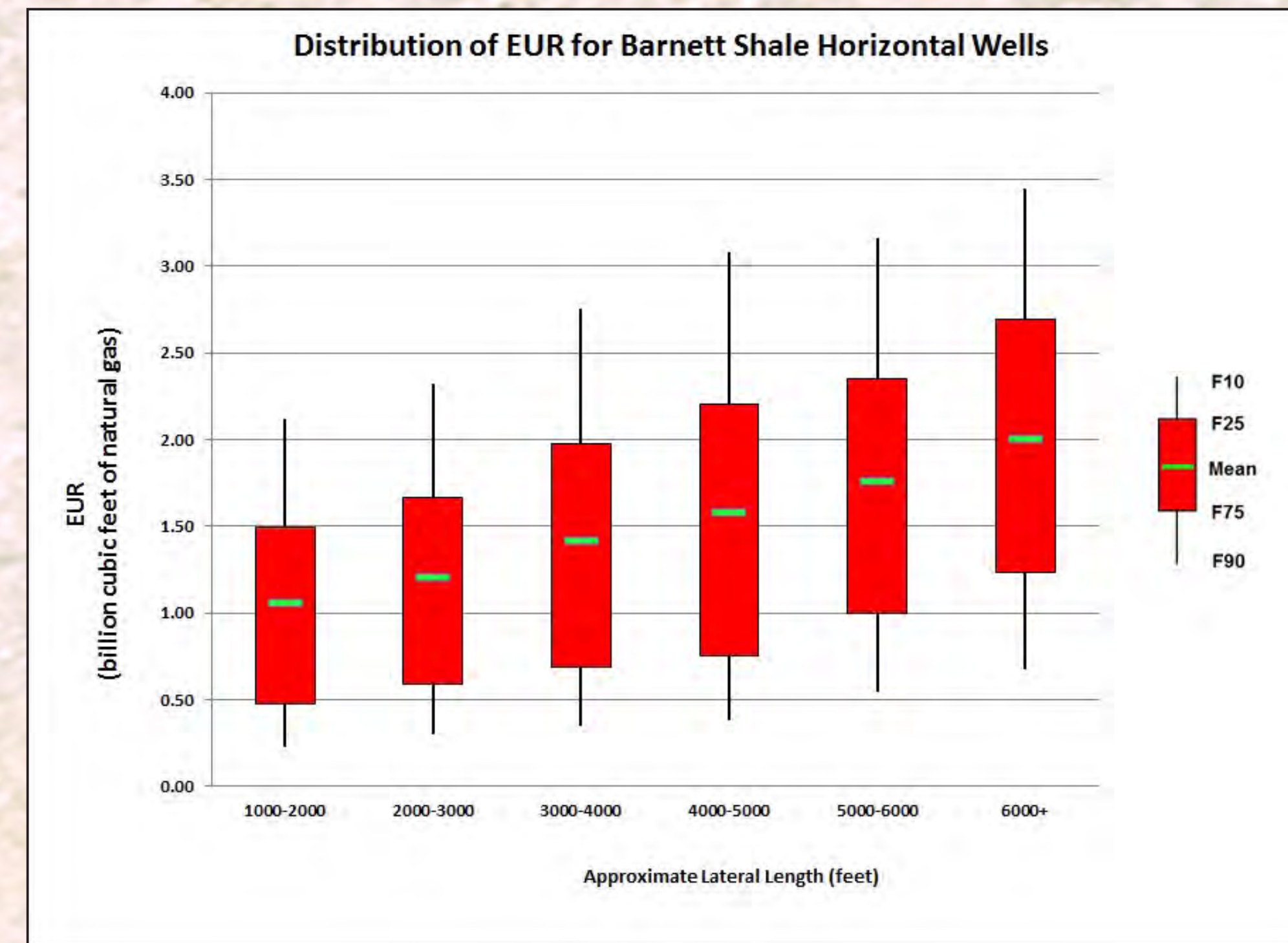### Changes in EUR with Horizontal Well Design

Figure 29. Plot showing increases in EURs for horizontal wells with increase in approximate lateral length. Approximate lateral length is defined as 80 percent of the horizontal difference between the surface location and the bottom-hole location.
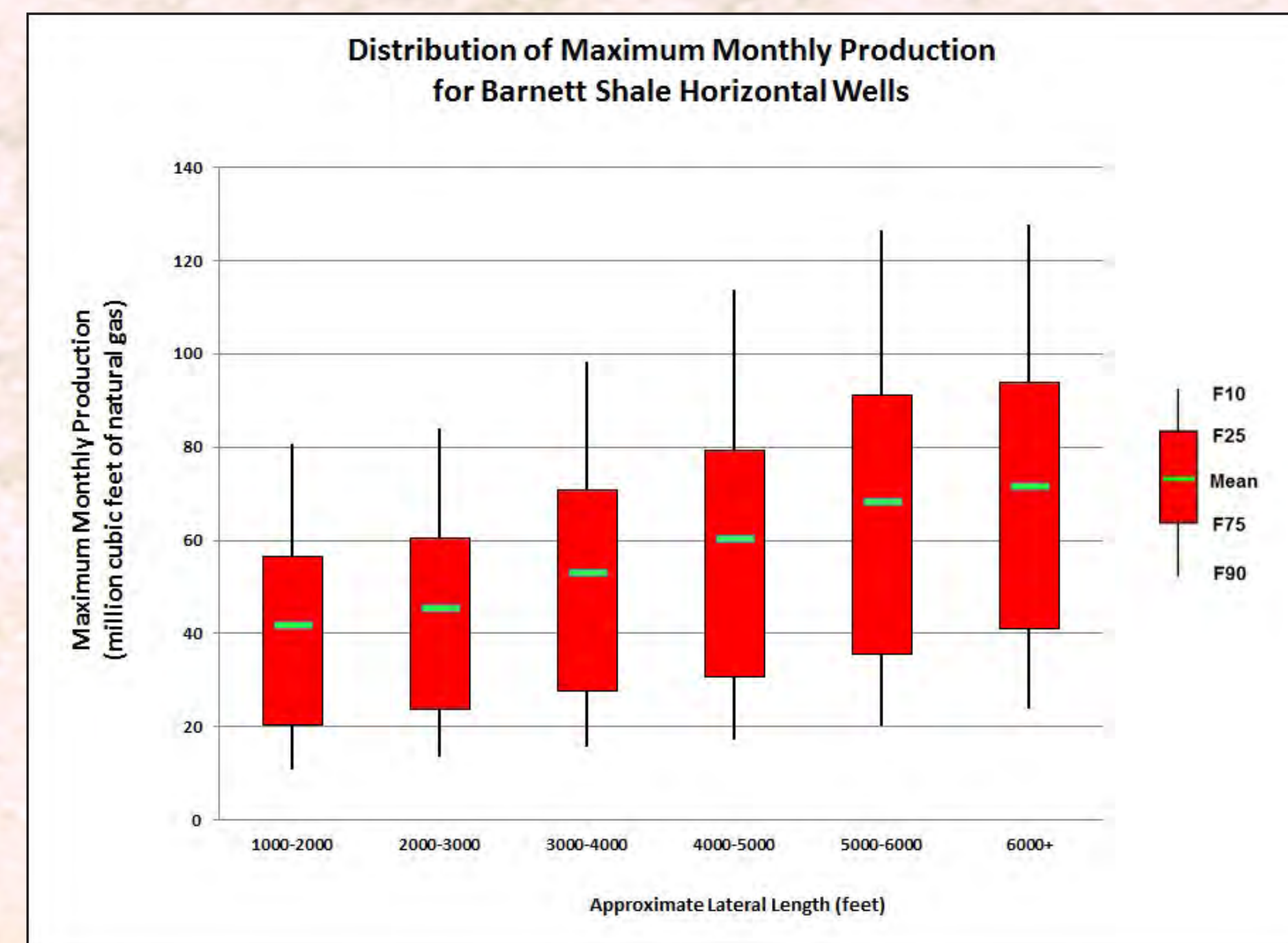
Figure 30. Plot showing decreases in EUR per 1000 feet of approximate lateral length for horizontal wells with increase in approximate lateral length. Although EUR increases with longer lateral length (figure 29), it does so with a diminishing rate of return.

Figure 31. Plot showing increases in maximum monthly production for horizontal wells with increase in approximate lateral length. Maximum monthly production is normally the first full month of production.
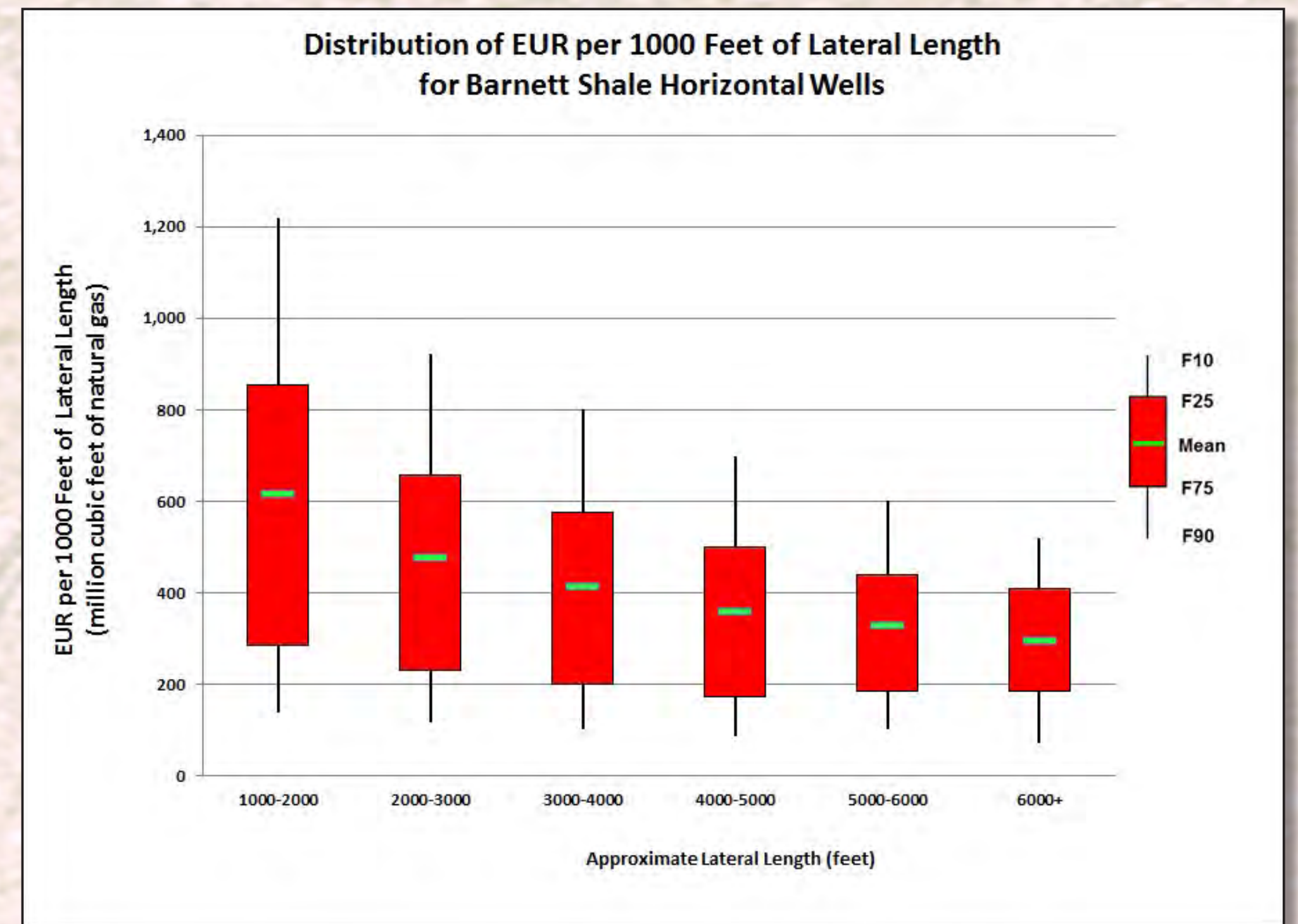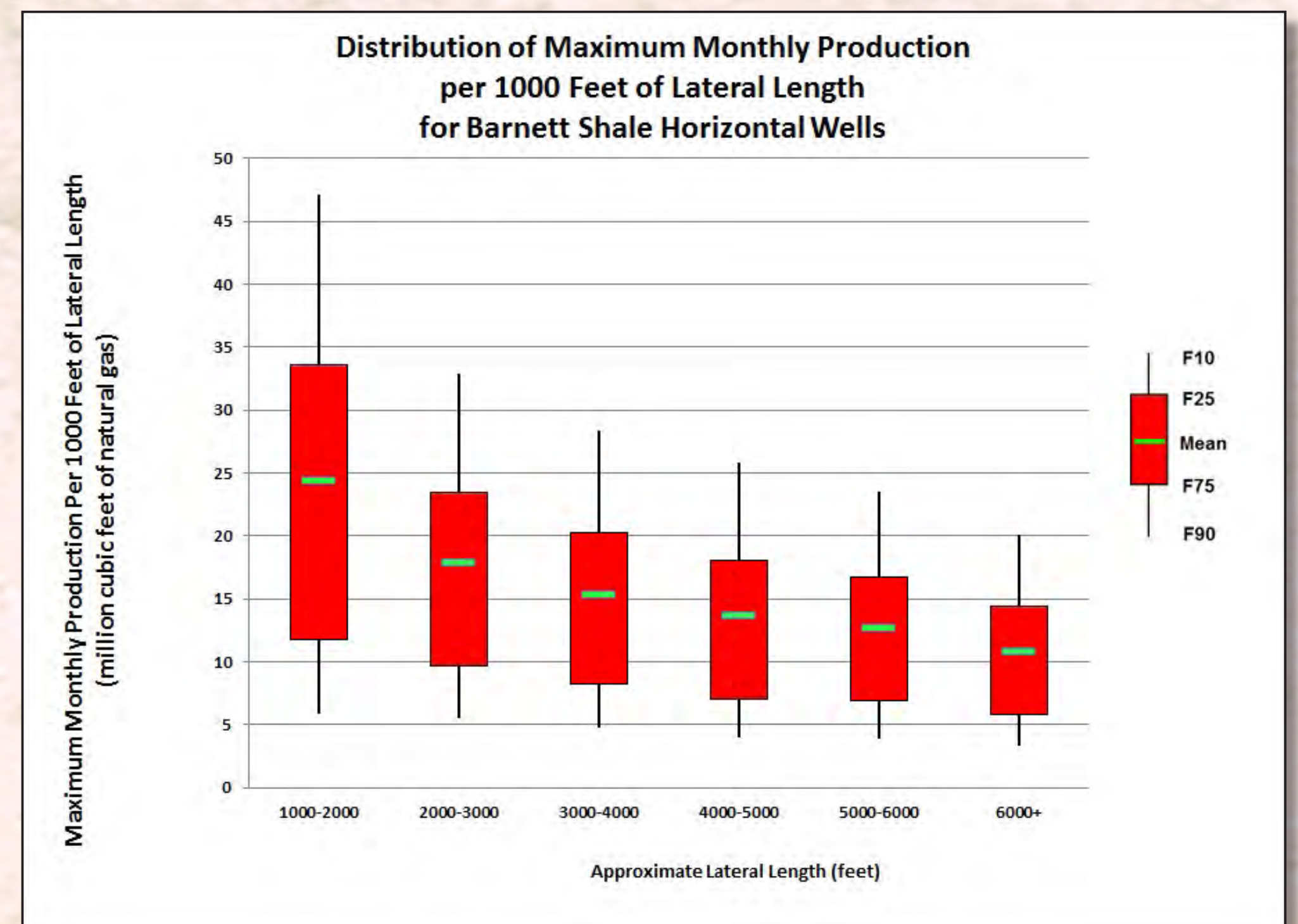
Figure 32. Plot showing decreases in maximum monthly production per 1000 feet of approximate lateral length for horizontal wells with increase in approximate lateral length. Although maximum monthly production increases with longer lateral length (figure 31), it does so with a diminishing rate of return.

Conclusions

Examination of oil and gas well productivities in continuous AUs shows a complex interaction of factors such as geologic variability and differences in well design. Analysis of the data can lead to better estimation of productivity for undrilled sites.

References Cited

Charpentier, R.R., and Cook, Troy, 2010, Improved USGS methodology for assessing continuous petroleum resources using analogs: U.S. Geological Survey Open-File Report 2010–1309, 27 p. Available at http://pubs.usgs.gov/of/2010/1309/.

Cook, Troy, and Charpentier, R.R., 2010, Assembling probabilistic performance parameters of shale-gas wells: U.S. Geological Survey Open-File Report 2010-1138, 17 p. Available at http://pubs.usgs.gov/of/2010/1138/.

U.S. Geological Survey Oil and Gas Assessment Team, 2012, Variability of distributions of well-scale estimated ultimate recovery for continuous (unconventional) oil and gas resources in the United States: U.S. Geological Survey Open-File Report 2012–1118, 18 p. Available at http://pubs.usgs.gov/of/2012/1118/.

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY