MULTI-WELL MANAGEMENT SYSTEMS
Part One - Gas Well Operations

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ABSTRACT

This paper presents a new methodology and software for management of gas wells. Graphical discovery tools and knowledge of field operating and engineering data are used to improve management of fields with large numbers of producing wells. The techniques are ideally suited for production of gas wells, including those producing under stripper market conditions. A pilot multi-well management system for a stripper gas field is demonstrated using LOWIS (Life of Well Information System) software by CASE Services, Inc. of Houston, Texas. Case history data is presented from the Hugoton Gas Field in western Kansas, and the Blue Ridge Field in West Virginia.

Being introduced is a new performance analysis method utilizing "Dynamic Baselines." This method is designed to take advantage of the continuous rate and pressure measurements in gas wells made possible by real-time, remote well surveillance systems. This technique offers a dynamic measurement of well performance through a continuous comparison of actual production to a predicted average or baseline cumulative production. Operations personnel find it useful for quick identification of wells whose production is beginning to lag due to mechanical or operational problems. Engineering personnel find it useful for optimizing the distribution of well recovery efficiencies throughout the field.

It is anticipated that one significant benefit of the technique will be for producing gas fields with large numbers of low volume, stripper wells. According to the Oil and Gas Compact Commission, there are approximately 230,000-stripper gas wells (defined as producing less than 16 Mcf per day) in the USA. It is hoped this methodology can become an economical method for daily surveillance and optimization of these types of wells. Further work is currently being done on application of these methods for optimization of oil wells under artificial lift, EOR operations, and high performance wells such as often found in new fields. Additional papers are anticipated on these topics in the future.

BACKGROUND

As a result of many operators investing in SCADA systems to remotely monitor their wells, a vast amount of valuable production data is now being automatically collected and stored in databases. This practice has already proven to be cost effective for monitoring purposes alone but considerable additional value is contained in the data if practical means can be found to utilize it. A major obstacle preventing analysis has been the lack of software tools to handle the shear volume of the data itself. One of the most promising methods of achieving this is through the use of what has become known as "graphical discovery tools". This type of software aims to reduce and then present the data in a manner in which trends and data of interest can immediately become noticeable.

The approach taken with LOWIS is to utilize graphical discovery tools adapted to the specific purpose of optimizing producing fields with large numbers of wells.

BASIC CONCEPTS

The foundation of the methods proposed in this paper rest on four basic paradigms, some of which are overlooked in conventional well analysis and surveillance processes.

Expanded Point-of-View

The well management process is enhanced when the focus is expanded beyond looking at individual wells to the trends, character, and performance of larger groups of wells. An analogy would be a flock of birds. By watching the whole flock in flight, their direction, speed, and reaction to weather and predators, one would gain information beyond that which could be obtained by watching just one bird at a time in the flock.

Time Dependent Correlations

Correlations between various data in a producing system can be time-dependent. Value can be added to the data by recognizing and modeling these shifting correlations.

High Frequency Data

The use of high frequency production data such as that now becoming commonly available through the use of SCADA systems, offers new opportunities. These new opportunities improve the well management process through the shortened recognition times possible for subtle or catastrophic disturbances within the system as well as the considerably more accurate and detailed information now available on well and system performance.

Integration of Other Relevant Data

Successful management of wells can be considerably enhanced when all available data on a well is integrated with the production data into a system used on a daily basis for well optimization. This includes geology and geophysical data, petrophysical data, reservoir data, operational data, and economic data.

MULTI-WELL MANAGEMENT SYSTEMS

The following definitions are useful in understanding the methods and concepts presented in this paper.

Performance Model

A LOWIS based graphical and analytical model capable of 1) continuously contrasting actual field performance for a specific set of variables with idealized or expected performance simultaneously for large numbers of producing wells, 2) performing customized surveillance functions using multi-well, time dependent correlations, and targets, and 3) managing the production optimization process for a producing oil or gas field at all levels including field, reservoir, and well. The primary engine of any LOWIS performance model is *The Trend Analyst*, a sub-system of the software. In addition, a performance model may have embedded data from other analytical components such as data distilled from geologic maps, nodal analysis, and total system flow simulators, material balance calculations, petrophysical data, bottom-hole pressure test, and even results from specialized artificial intelligence tools, etc.

Multi-Well Management System (MWMS)

A collection of LOWIS Performance Models graphically integrated and specially adapted for management of a specific field. The complexity of the performance model can vary with the specific requirements and budget for any given project. A complete model would include all types of G&G, engineering, operations, and economic data, infill drilling results, etc. In addition, Best Field Operating Practice and Rules can be very useful additions.

The primary purpose of all Performance Models and Multi-Well Management Systems is to optimize the production of hydrocarbons from the field, both from a technical and economic perspective.

A complete Multi-Well Management System for gas wells should include the following components:

1. Electronic flow meters and communication systems for producing wells

2. SCADA system (can be an advanced system such as LOWIS or any other SCADA system)

3. A means to integrate data from all relevant corporate databases. If LOWIS is used, this functionality is already available.

4. A collection of performance models tuned for a specific field

DYNAMIC BASELINES

Dynamic baselines are used in Performance Models and designed to continuously compare the actual well performance with an average or expected performance baseline, which is shifting in time. It requires daily rate measurements, which are then used to compute the other necessary variables. Since the method involves a comparison between individual well performance and the performance of a group of wells, it is required that the wells have certain common parameters such as the same producing formation, similar completion methods, and a common gathering system and compressor (if present).

The dynamic baseline simply described, is merely the average performance of the group wells throughout time. To determine this, it is first necessary to calculate a running cumulative production from time zero of the analysis (usually defined as the date that the SCADA system was activated in the field) for every well. Then, for each time step, the rate vs. cumulative production for all wells are all plotted on the same graph. A least squares best-fit line and its slope is then determined at even time increments though the time span of the historical data. An equation can then be developed to model the average or baseline performance for that time step (refer to Figure 3 for an example). Three simple equations are used to input the dynamic baseline data into the Performance Model. (Refer to Figures 2 and 3 for more information)

Slope Function

Eq. 1 … $m(t) = a * t^{-b}$

Where *m* is the slope function from the time slices on the Rate-Cum (R-C) plot, *a* and *b* are constants, and *t* is time interval, normally in days or hours as measured from t_0 (usually the time when the SCADA system was first activated).

Best Cum Equation

Now that we have an equation describing the slope of the baseline at any time, it can then be applied to characterize well performance. For each time step, the predicted R-C slope of the baseline is first computed. Then, using this R-C slope, the daily rate of the well is used to determine the average expected cumulative production (or Best Cum) for the whole group. Equation 2 characterizes this:

Eq. 2… Best Cum = Rate/m

Where *Best Cum* is the predicted cumulative production at time *t* using the baseline slope function, *Rate* is the actual rate of the individual well at time *t*, and *m* is the slope as determined at time *t*.

Lead-Lag Equation

The difference between the actual cumulative production and that predicted by Best Cum is then used to determine lead-lag. This lead-lag variable can be thought of as a measure of how much a well's cumulative production is leading or lagging behind what its cumulative production could have been at any given time if it was performing as an average well in the control group. Lead-Lag is defined by Equation 3.

Eq. 3… Lead-Lag = Actual Cum Production – Best Cum

Where *Lead* is a positive number and *Lag* is a negative number.

The cumulative lead-lag over time can reveal useful information on a real-time basis for field operations staff when it is cross-plotted against such variables as cumulative down-time of the well. Likewise, when cross-plotted against remaining reserves it can be a valuable aide to recovery management. See the Blue Ridge Case History below for an example.

To analyze well performance, the cumulative lead-lag for each well is first plotted against another relevant variable like downtime or remaining reserves. At t_0, the cumulative lead-lag for each well should be zero. Then, stepping through the different time steps, wells can be seen to either rise or fall away from the zero baseline. Wells that rise above the baseline are said to be "leading" because they are producing more than expected. Likewise, wells that fall below the zero baseline are said to be "lagging" because they are consistently producing less than their capability. The graphical plot of this can be quite informative, especially when large numbers of wells are displayed simultaneously.

The behavior of the wells becomes apparent when this graph is animated through time. Some wells are seen to consistently lead or lag behind the others. These wells can be short-listed for more in-depth analysis.

OTHER METHODS EMPLOYING DATA INTEGRATION

In addition to dynamic baselines, other useful types of plots can be included in Performance Models. One such plot is the Cross-Hair Plot, an example of which is shown in Figure No. 10. This particular plot is from a multi-well management system made in part of the Hugoton Gas Field in western Kansas. The plot is time animated and shows cumulative, normalized flow rate versus cumulative, normalized flowing tubing head pressure for a group of wells all sharing a common gathering line and compressor. The plot has additional data embedded into it from bottom-hole pressure build-up tests. This data was used to determine productivity indexes on the wells. Over a long period of time, the deterioration of productive index on specific wells was determined from well test data. Each well in the plot has a symbol indicating the amount of decrease in productive index.

This Cross-Hair Plot was then linked to several other plots including a dynamic baseline plot and one showing key geological data. The results proved quite valuable for the selection of wells for fracture treatments as well as for determining which types of fracture treatments were most effective.

CASE STUDY – THE BLUE RIDGE GAS FIELD

Many of the methods discussed in the above are illustrated in a case history from the Blue Ridge Field located in West Virginia on the Appalachian Plateau. The wells are producing from Paleozoic rocks at an approximate depth of 4500 to 5000 feet. Specific formations included the Big Line, Big Injun, Weir, and Devonian Shale. Production operations had been ongoing since 1995. Electronic Flow Meters were activated in February of 2003. The pilot Performance Model was built in November 2003 and zeroed to February 2003 when the EFM's were turned on. The model was only a pilot test before the construction of a much larger Multi-Well Management System.

Results from the pilot model will be shown during a live demonstration at the Southwestern Petroleum Short Course. Screen captures and further discussion are included in the figures at the end of this paper. See Figures No. 5, 7 and 9 for some of the optimization recommendations that were generated from the model.

LIMITATIONS

It is important to note that several limitations on the Dynamic Baseline concept need to be kept in mind when applying this methodology.

1. To-date, the methodology has only been tested on gas fields. Further work is underway at CASE Services to develop applications to oil wells.

2. At this time, it is only recommended to use this method on fields where the majority of the gas wells are equipped with Electronic Flow Meters. Work is being done on methods for incorporating data from orifice meters with pen and ink chart recorders.

3. The methodology is affected by wells that are shut-in during portions of the time period during which the dynamic baseline analysis is carried out. Further work is being done to allow the software to accommodate these types of anomalies, but at the current time, wells with large amounts of shut-in time do not work well in the dynamic baseline model.

4. Dynamic Baselines work best with real-time production data over short analysis periods. Different time periods offer insight into different phenomena. A short time period (one to three months) will be affected mainly by well-specific conditions, whereas a long timeframe (one or more years) will offer more of an insight into reservoir performance. At present, one year is suggested as a reasonable maximum time frame although it is anticipated that this time interval will increase as more experience in applying the methodology is obtained.

BENEFITS

Due to the wide range of applications for methods discussed in this paper, a substantial range of benefits is possible. Listed below is a short-list of benefits taken from the Hugoton and Blue Ridge applications discussed in this paper.

1. Increased awareness of field operating practices and conditions by engineering personnel that influence reserve recovery and well performance

2. Increased awareness by operations personnel of corporate reserve assets and how field operating practices are influencing reserve recovery efficiency

3. Identify, on a real-time, multi-well basis, those field operating conditions that may be negatively influencing well performance and reserve recovery

4. Develop recommendations for accelerated or more efficient reserve recovery including compression upgrades, flow-line modifications, well workovers, and stimulation treatment

CONCLUSIONS

Multi-Well Management Systems are an invaluable tool for optimization of gas fields whose time has come. It is now possible to extract additional value from the large amounts of high frequency data being collected from SCADA systems in gas fields. Software is available for this purpose and can be expected to improve in capability with time and exposure to different applications. New analysis methods are also being developed and will increase in sophistication with time and use.

This is the first in a series of papers on Multi-Well Management Systems.

FIGURES

The following figures are extracted from a live demo of the performance model constructed for the Blue Ridge Field using LOWIS software. Some of the figures are referenced in the text of the paper, and some of them contain new information not included in the paper.

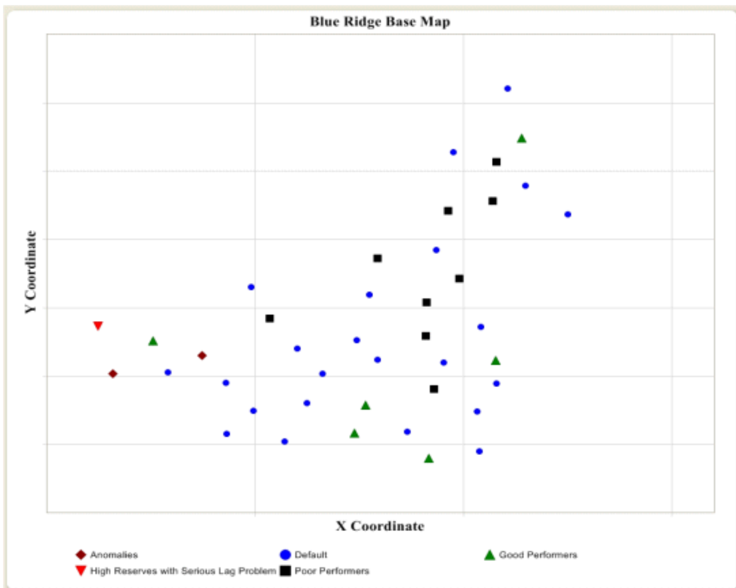

Figure 1 – The Blue Ridge Field is located in West Virgina on the Appalachian Plateau. The wells are producing from Paleozoic rocks at an approximate depth of 4500 to 5000 feet. Specific producing formations include the Big Line, Big Injun, Weir and Devonian Shale. This map shows only a small portion of the entire field.

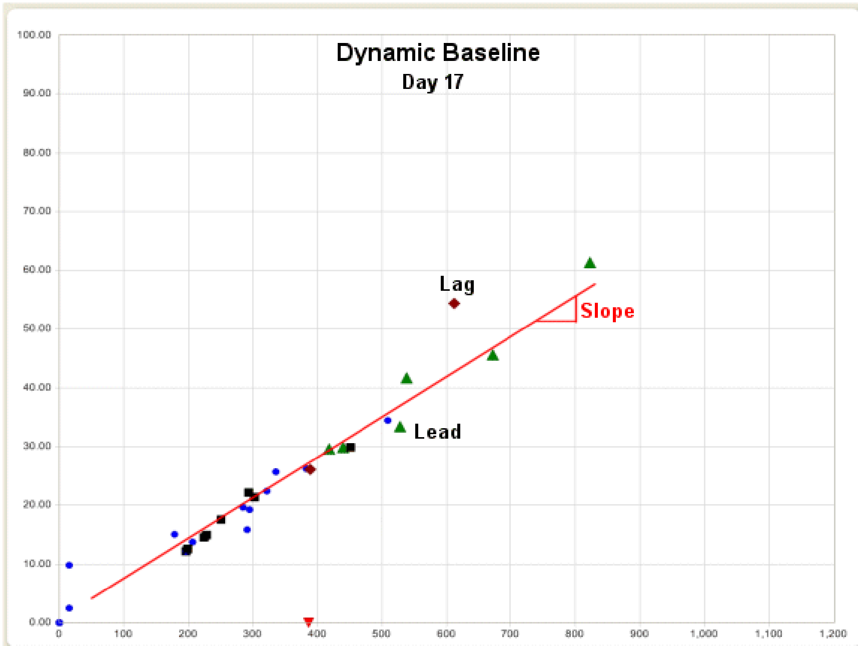

Figure 2 - This figure shows one time slice in the construction of a dynamic baseline. Rate is plotted on the Y-axis and cumulative rate on the X-axis. The red line represents the least squares, best-fit line. The slope of this line is used to generate a slope function as shown in Fig. No. 3. See the section titled Dynamic Baselines for more details.

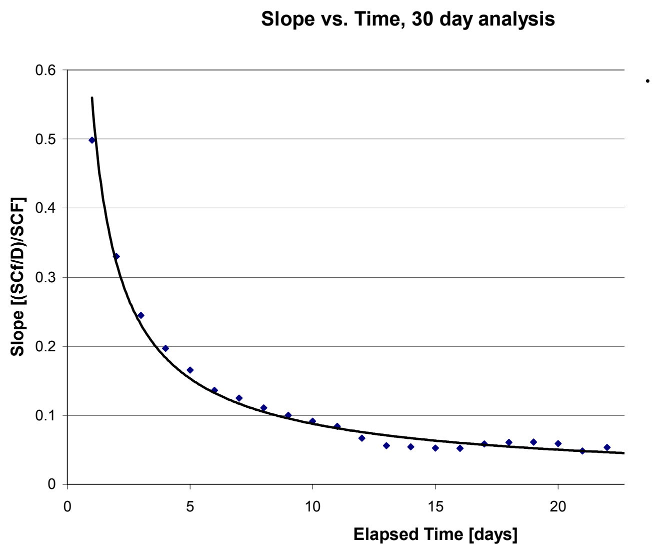

Figure 3 - This is the plot from which the best-fit slope function was generated. A number of time slices from Rate vs. Cum Production plots, such as that shown in Fig. No. 2, were used to generate Fig. No. 3. This slope function is for a short-term study with a 30-day time period. See the section titled Dynamic Baselines for more details.

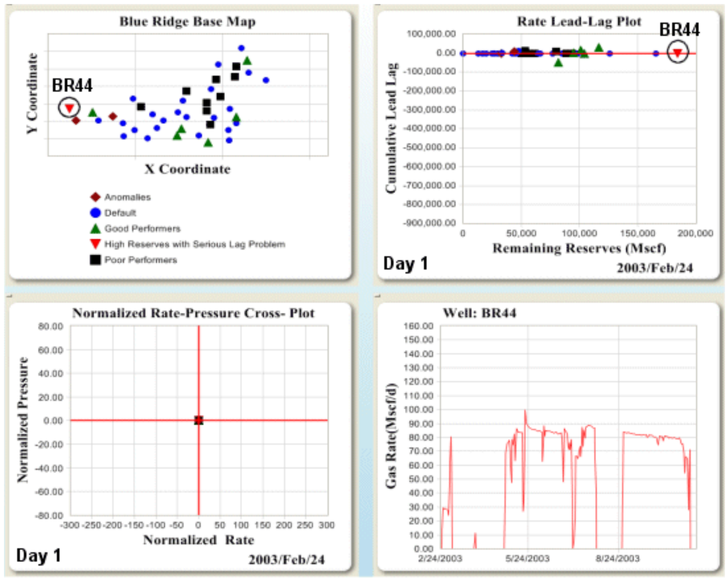

Figure 4 - The four performance plots in this figure are part of a multi-well management system for the Blue Ridge Field. The key plot in this instance is the Lead-Lag plot in the upper left. Note that Lead-Lag is plotted versus Remaining Reserves. This is part of an animation sequence. This particular plot is taken at the beginning of the sequence, or Day 1.

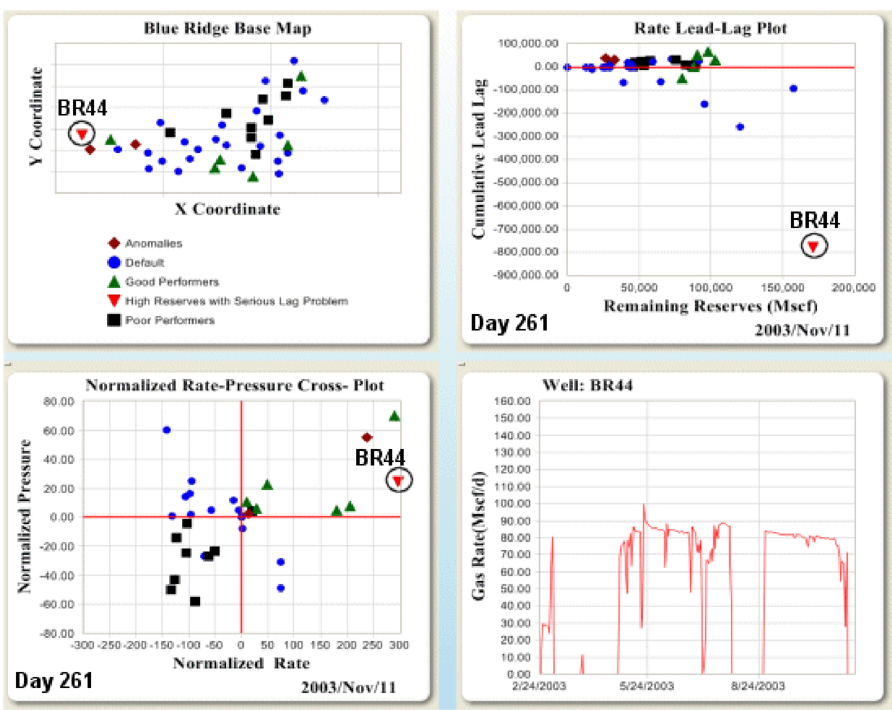

Figure 5 - This is the same plot as in Fig. No. 4, except at Day 261. Note that the wells have moved in the Lead-Lag and Cross-Hair plot. One significant discovery was the well BR 44, which had the highest remaining reserves, was significantly lagging compared to its expected performance due to inadvertent shut-ins. This fact had gone un-noticed since the operator had literally thousands of such wells to operate with little time to check individual wells for such problems. Recommended Action: Evaluate causes of BR 44 shut-ins and eliminate if possible.

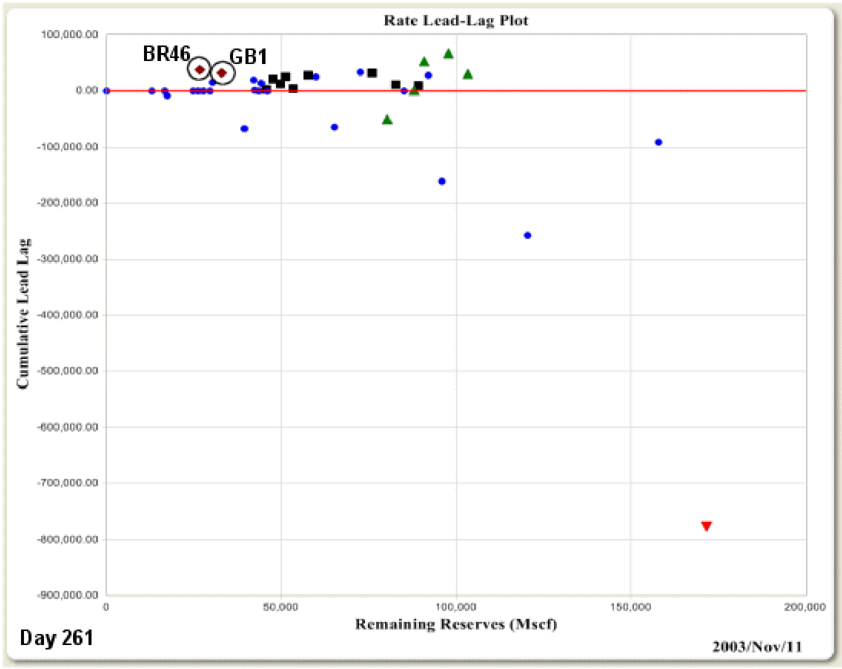

Figure 6 - This figure shows an expanded view of the Lead-Lag plot versus Remaining Reserves shown in Fig. No. 5. Using this plot and the others included in Fig. No. 5, the BR 46 and GB1 wells were discovered to have an interesting anomaly. Note that both wells are in a Leading position, but have some of the lowest remaining reserves. See Fig. No. 7 for a rate plot of BR 46 which identifies the anomaly.

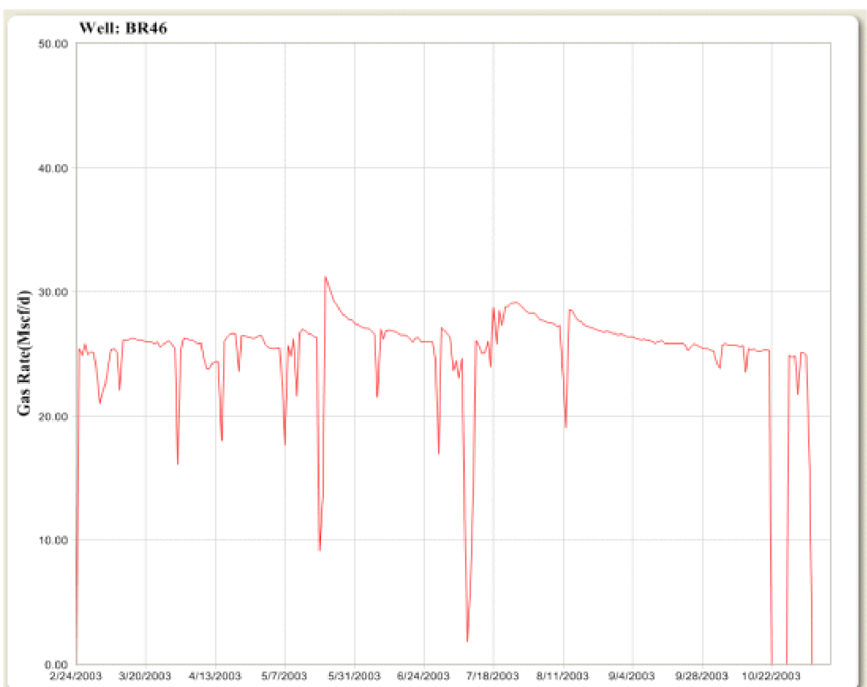

Figure 7 - This is the rate versus time plot taken from Fig. No. 5 for BR 46.
The production rates for both this well and GB1 are not declining, even though the wells are indicated on the Lead-Lag plot to have very low reserves. This anomaly leads to the possible suspicion that these two wells have higher reserves than previously thought. Recommended Action: Re-evaluate the reserves in this area of the field.

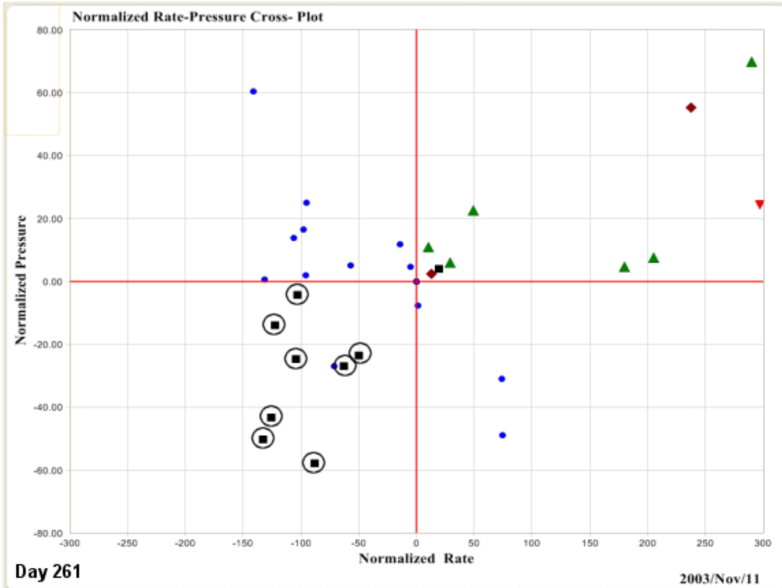

Figure 8 - This is the same Cross-Hair plot as shown in Fig. No. 5. The wells shown in the lower left quadrant all have unexpectedly low cumulative normalized rates and pressures and need further investigation. See Fig. No. 9 for further data of relevance to this problem.

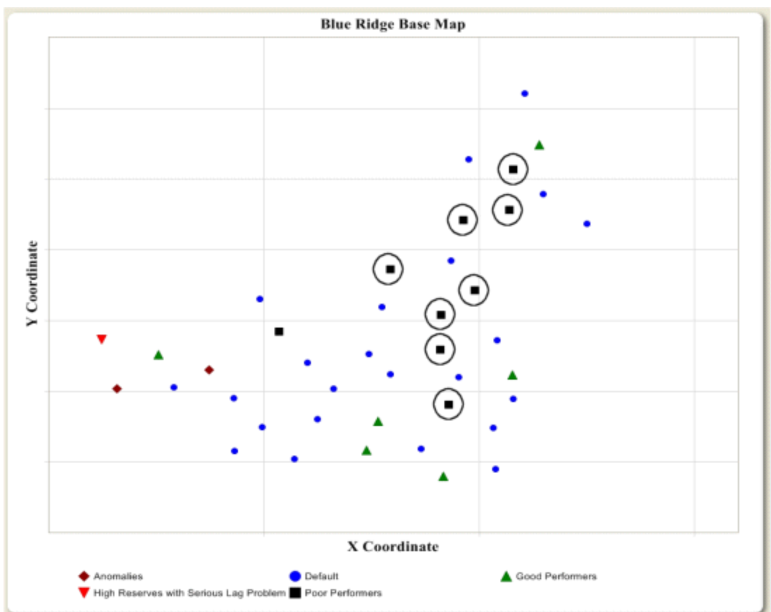

Figure 9 - This is the same Base Map as shown in Fig. No. 1. It shows the location of the poorly performing wells identified in Fig. No. 8. Note that they are all in the same area. Further investigation revealed that they were all connected to the same lateral and compression system.

Recommended Action: Evaluate the lateral for possible restrictions in low spots on the gathering line, or check the possibility that a compressor expansion might be justifiable

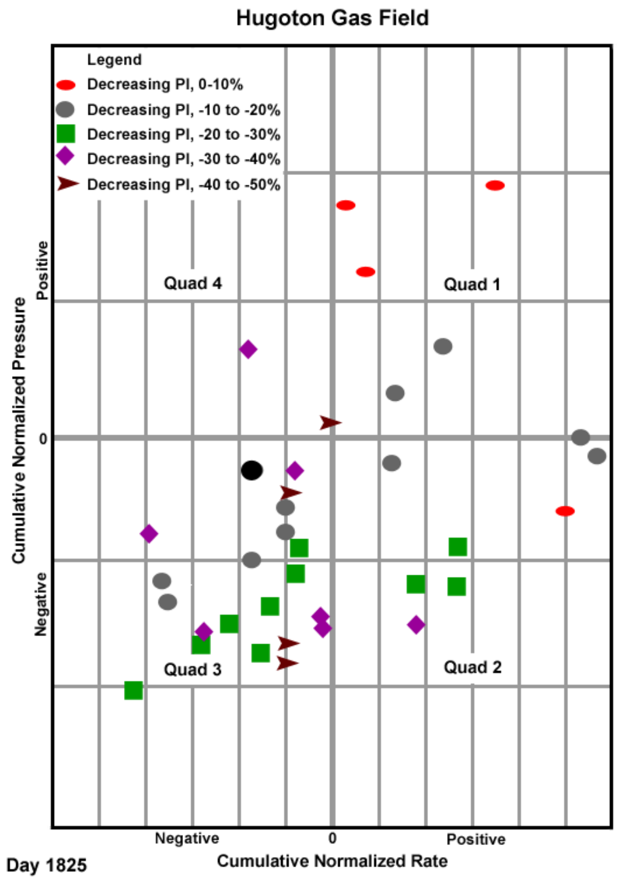

Figure 10 - This is a Cross-Hair Plot showing Cumulative Normalized Flow Rates of individual wells on the X axis and Cumulative Normalized Tubing Head Pressures on the Y axis. It also has descriptive symbols for individual wells which indicate interpretative estimates of changes in productivity indexes over a five year time period. This figure was taken from an animated sequence of similar plots. Data from this and other plots was used to develop “performance quadrants”. These are indicated on the plot. After calibration with the PI and well test data, they were interpreted as as shown below. This plot was used for determining what action was necessary for other wells with no test data.

Quad 1 Strong wells, could benefit from a drop in line pressure

Quad 2 Good wells. Good pressure draw down from the compressor

Quad 3 Weak wells. Good pressure draw down from the compressor. Stimulation candidates

Quad 4 Weak wells. Could benefit from a drop in line pressure. Possible stimulation candidates

Note: Only wells with well test data are shown. Other wells were included in the plot, but are not shown.