What about Deffeyes' Prediction that Oil will Peak in 2005?

In the mid 1990's Campbell and Laherrere[1] pioneered the alert scenario that world conventional crude oil production would peak in the not too distant future and predicted that it should occur between 2000 and 2010. Their projected peak for conventional crude oil production was 66 - 77 million barrels a day on the assumption of an estimated ultimate recoverable reserves (URR) value ranging between 1,750 and 2,250 billion barrels (Gb). Their methodology consisted of a detailed analysis of production history and discovery trends in several important oil producing countries. In addition, they incorporated projections of probable reserves yet-to-be-found in the different oil basins around the globe. They specifically raised several objections to the logistic model, which Hubbert had successfully used in the past to predict that U.S. oil production would peak in 1970, as it actually did. Many other critics have argued that Hubbert's prediction was just an accidental coincidence.

In 2001, Deffeyes[2], a colleague of Hubbert, published his prediction using Hubbert's logistic model, that world oil production would imminently peak in 2005. He also estimated that the URR would be approximately 2000 Gb, of which 850 Gb had already been produced at the end of 2000. A simple graph (Fig. 1) of world oil production over the last 100 years leaves no doubt that Deffeyes' peaking prediction is an ongoing event. (*Note that the outliers in Fig. 1 correspond to the recession of the 1980's. A graph of production rate from the 1990's onward (inset in Fig. 1) would evidently show an illusory, unfettered growth rate*). It is a well-known fact that oil supply has been struggling to meet demand since 2001, with no obvious response from higher oil prices. Prices topped the $50 a barrel barrier last November and in June 2005 had soared to a $60 a barrel high. The demand for oil is created by economic growth and both the U.S. and Chinese economies - the world's two top oil consumers - are growing at a pretty good clip.

Following the publication of Deffeyes' book, strong and even caustic critics of Deffeyes' results, and in particular of the logistic model itself, flourished and continue to do so. A recent feature article in Time magazine, May 9, 2005, titled: "Why gas won't get cheaper", stated that "energy experts obsess over whether we've reached Hubbert's Peak" and went on to claim that "at some point in the next decade or so – estimates range from 15 to 25 years – the world's oil production will peak." In another recent article in Oil & Gas Journal on June 6, 2005, Cavallo states that "his analysis shows that Hubbert's model cannot predict ultimate oil reserves".. Even the more complacent critics of the logistic model contend that the estimated URR is a moving target since its value depends on future exploration and production technology, and on future oil prices. Although these assertions are theoretically correct, what is important and often missing in most analyses is how

[1] "World Oil Supply 1930-2050", Campbell, C.J., Laherrere, J.H., Petroconsultants, Geneva, 1995.
[2] Hubbert's Peak – the Impending World Oil Shortage, Deffeyes, K.S., Princeton University Press, 2001

they impact the decline curve. The examples used in this study were chosen to address these and other special effects.

Granted it may be mind-boggling to accept that a simple straight-line extrapolation of a plot of annual decline rate versus cumulative production could provide an estimate of the ultimate recoverable reserves of oil on the planet. However to its credit, the logistic model is one of a family of models[3] used routinely in the oil industry since the 1940's to appraise reserves of oil wells and reservoirs by decline curve analysis. These models, generally referred to as exponential, hyperbolic and harmonic, have been used effectively to replicate the behavior of reservoirs producing under a wide range of mechanisms varying from natural in-situ water and gas cap drives to fluid injection. The logistic equation is merely a modified version of the exponential decline model, extended to match the behavior of oil fields and, ultimately, of oil producing regions or countries.

The object of this article is to demonstrate the applicability of the logistic decline model to three mature giant oil fields for which their URR has been established by more sophisticated numerical simulation techniques. The analysis is further extended to the Big Three oil producing countries (USA, Russia and Saudi Arabia) to look at the impact of well documented issues such as discoveries and market fluctuations on their decline curves.

Reserves Evaluation Basics

Prior to start-up of production, volumetric evaluation of reserves based on geologic and raw engineering data - porosity, saturation, areal coverage and formation thickness - is the only option. As production data becomes available several methods based on reservoir performance, such as production decline analysis and reservoir simulation, provide more accuracy in the reserves estimate. Decline curve analysis is generally regarded as one of the primary tools for reserves evaluation largely because of its simplicity and reliability. Since it is based entirely on measured production data, decline curve analysis distinctively provides an estimate of *proven* reserves.

The logistic model is defined as:

$$(dQ/dt)/Q = r_o(1 - Q/K) \qquad (1)$$

where Q is the cumulative oil production, (dQ/dt)/Q is the annual percentage production decline rate, r_o is the initial production decline rate, and K a capacity constant. The Q/K term represents a physical constraint, namely, that the final production of the field is limited to the capacity or amount of recoverable oil. K is therefore the ultimate recovery (URR) of the field, and (K – Q) the remaining reserves at any time t. A plot of the annual percentage decline rate versus

[3] Arps, J.J., AIME Trans., 160 (1945), p. 228

cumulative production is a straight line which can simply be extrapolated to Q = K, the URR value.

However, *prior* to determining the beginning of the straight line portion of the logistic model to be extrapolated, several conditions must be met. The most important of these is that production decline be in a stabilized mode. This occurs *after* the end of the early production period. During this early period, Q/K << 1 and Equation (1) reverts to:

$$dQ/dt = r_o Q \qquad (2)$$

which is the familiar exponential model used widely in well and reservoir analysis. Production rate (dQ/dt) versus cumulative production (Q) plots as a straight-line through the origin Q = 0. When this trend breaks down, it is indicative that production is entering the decline phase. As a rule of thumb, the decline curve stabilizes after approximately 20-25 percent of the original reserves have been produced. These behaviors will be illustrated later on in this article.

Estimating Reserves of Three Giant Oil Fields

The logistic decline method was applied to the production data of three giant oil fields, namely, Prudhoe Bay (USA), Romashkino (Russia) and Furrial (Venezuela). They were chosen to illustrate the decline behavior under different drive mechanisms. Prudhoe Bay has a natural gas-cap drive which was complemented with water injection early in the life of the field. Both the Romashkino and Furrial fields have natural solution-gas drives which were complemented with water and gas injection, respectively, late in the life of both fields. The decline behavior of other giant fields producing under different dynamic conditions is discussed in another paper[4].

Figs. 2-4 illustrate the stabilized portions of the decline trend lines and the corresponding extrapolated URR values for the three fields. The suitable straight-line portion of the logistic curve is easily selected in these cases because the fields are all mature. In the case of the Romashkino field, the straight line exponential plot is also shown as an inset in Fig. 2. The straight line from the origin represents the early production period which ended in 1958, eight years after the field was first put on production. The decline curve for this field exhibits two straight line portions. The first ends at 1987 and extrapolates to an URR value of 14.8 Gb. Water injection started in 1987 and altered favorably the decline trend which extrapolates to a new URR level of 15.2 Gb. The field is essentially depleted and has produced 96 percent of its URR.

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[4] Early Estimation of the Onset of an Oil Field's Peak Production, Sandrea, R., August 17, 2004. Available at www.its.com.ve.

Prudhoe Bay exhibits (Fig. 3) a single decline rate trend line which has built-in the effects of a water injection program which was implemented from the very start of production. The trend line extrapolates to an URR value of 11.5 Gb of which 10.7 Gb (93 percent) had been produced at the end of 2004.

In the case of Furrial, production start-up was in 1986. The latest straight line trend (Fig. 4) corresponds to a gas injection program initiated in 1997, after the field had produced 45 percent of its original reserves. The current trend extrapolates to an URR value of 2 Gb. The field has produced 82 percent of its ultimate recoverable reserves.

These examples demonstrate the strength of the logistic decline curve as a reliable tool for estimating reserves in a closed system - one in which discoveries and developments occur in a confined interacting entity - as is characterized by an oil field. The decline curve adequately accounts for the developmental phase of the field which may include additional discoveries and/or field extensions, and any enhanced recovery programs that may be implemented during the life of the field. The predicted URR values for the fields in this study are in actual fact the true URR's since all three fields are essentially at the end of their productive lives. The extrapolated URR values were obtained from a least squares fit of the trend lines.

Estimating Reserves of the Big Three Oil Producing Countries

In contrast to oil fields which are closed systems, basins, countries and oil regions are open systems. For all intents and purposes these consist of multiple independent oil fields, each discovered and developed in different time intervals. In this phase of the study, the decline behavior of the three largest oil producing countries: USA, Russia and Saudi Arabia, is analyzed. Together these three countries account for one-third of the world's conventional crude oil reserves and of its daily production.

In the case of the U.S., production began in the 1850's and went into steady state decline during the period following WW II, 1945-1950. Ever since, the decline curve (Fig. 5) has exhibited a single straight line trend which extrapolates to an URR value of 225 Gb. There are two events of interest that could have impacted the stabilized decline curve. First, the discovery of the largest oil field in North America, Prudhoe Bay. Production in this field began in 1977, reaching a maximum of 560 million barrels a year by 1981. A minor blip of this episode is discernible on the decline curve in 1985. Apparently, Prudhoe Bay's URR of 11.5 Gb (less than 5 percent of the USA's URR) did not have sufficient clout relative to the heavy chunk of reserves that the U.S. was producing - 3.2 Gb a year - at that time.

The second important event in the U.S. production history was market related. Production dropped substantially from a high of 10.6 million b/d in 1985 to 8.9 million b/d in 1990 during the recession. As shown in Fig. 5, only a slight effect on the country's overall decline trend is observed in 1990. The U.S. had produced 185.4 Gb of crude oil or 82 % of its URR through 2004.

In retrospect, Hubbert's 1962 prediction of an URR of 200 Gb for the U.S. was outstanding. At that time production decline was in a stable mode for roughly 10 years. The fact that this initial trend essentially remained unbroken - in spite of new discoveries and market fluctuations - was undeniably very favorable to his early results.

Let's now look at the Russian data (Fig. 6). In this case, steady state decline kicked-in during the early 1970's and the trend has essentially remained unchanged albeit production set-backs during the 1990's (shown as outliers in Fig. 6) following the end of the Soviet era. The events of interest in Russia are the discovery of the giant Samotlor field (URR, 15 Gb) in 1965 and the build-up of production to 4 Gb a year by 1980. Again, only a minor blip is perceptible on the decline curve as of 1980. The Samotlor event occurred *before* the decline curved stabilized. Russia's extrapolated URR is 195 Gb of which 147.7 Gb (75 %) had been produced at the end of 2003.

Saudi Arabia is an interesting case. Production began in the 1940's and grew steadily through 1981 when the country's output was severely affected by the then approaching world recession. The decline curve had just begun to stabilize during the period 1975-80 (Fig. 7). Production subsequently dropped sharply (64 percent) from a high of 3.7 Gb a year. Decline stabilized once more in the mid 1990's. This new trend generates an extrapolated URR value of 165 Gb of which 97.3 Gb (59%) had been produced through 2003.

Closing Remarks

- **The logistic decline model commonly known as the Hubbert model, has been shown to be a reliable tool for predicting reserves in individual and conglomerates of oil fields. The latter would represent the case of producing countries and oil regions.**

- **Decline curve models have well served the oil industry since the 1940's in the appraisal of oil wells and reservoirs. They do not derive from physical laws as such but neither are they simple econometric models. Their success lies in the application of a good engineering/geologic analysis of the data to determine key issues such as the onset of steady state conditions, identification of outliers (output disruptions and the like) in the data points, and operational changes (discoveries and new fluid injection projects) that may affect the trend line. In the case of the logistic model the trend of interest is a simple straight line.**

- **The logistic decline model utilizes exclusively production behavior to estimate reserves. These estimates are therefore, by definition, proven reserves and do not include yet-to-find reserves. The latter have to be established by other techniques.**

- **Deffeyes's decline prediction of an ultimate recovery of the world's conventional crude oil supplies to be 2000 Gb and peaking in the year 2005 appears to be on track. Peak production occurs at the half-life of the ultimate reserves or 1000 Gb. At current production rates, the world would reach this threshold about mid 2006.**

- **The world's remaining reserves of roughly 1000 Gb of crude oil have a duration of 40 years at current production rates.**

- **The world is also known to have substantial unconventional extra-heavy crude oil and bitumen resources. Canada and Venezuela possess approximately 3000 Gb and Russia, 1400 Gb. Other significant heavy oil resources are also found in the U.S. (200 Gb), Kazakhstan (80 Gb) and Madagascar (20 Gb).**

Finally, we have a fairly good grasp of the remaining oil inventories. Now is the time to focus not only on developing alternative sources of energy but also on making prudent use of the existing reserves.

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Rafael Sandrea
July 25, 2005

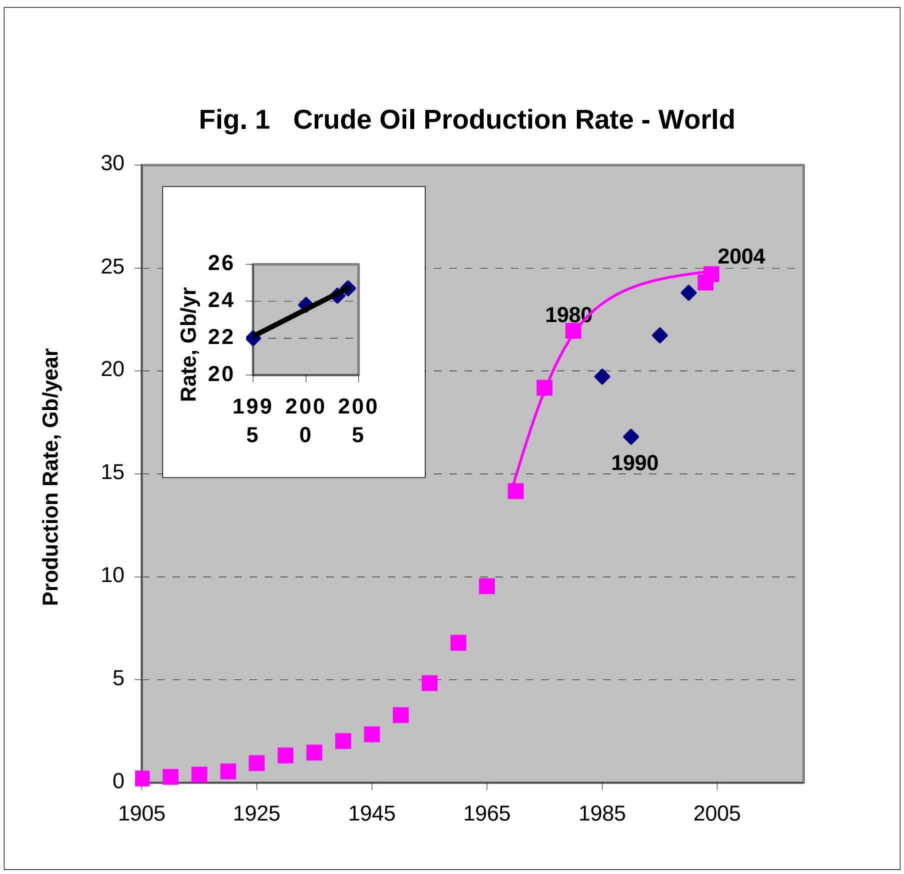


Fig. 1 Crude Oil Production Rate - World
Production Rate, Gb/year
30
25
20
15
10
5
0
1905
1925
1945
1965
1985
2005
1980
1990
2004
Rate, Gb/yr
26
24
22
20
199 5
200 0
200 5

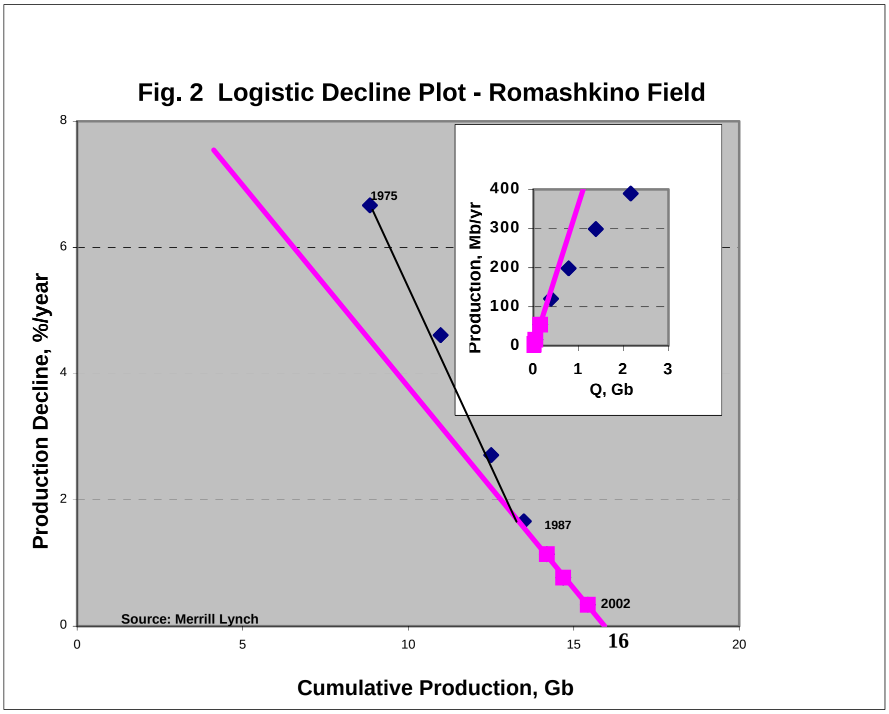


Fig. 2 Logistic Decline Plot - Romashkino Field
Production Decline, %/year
Cumulative Production, Gb
0
2
4
6
8
0
5
10
15
16
20
1975
1987
2002
Source: Merrill Lynch
Production, Mb/yr
Q, Gb
400
300
200
100
0
1
2
3

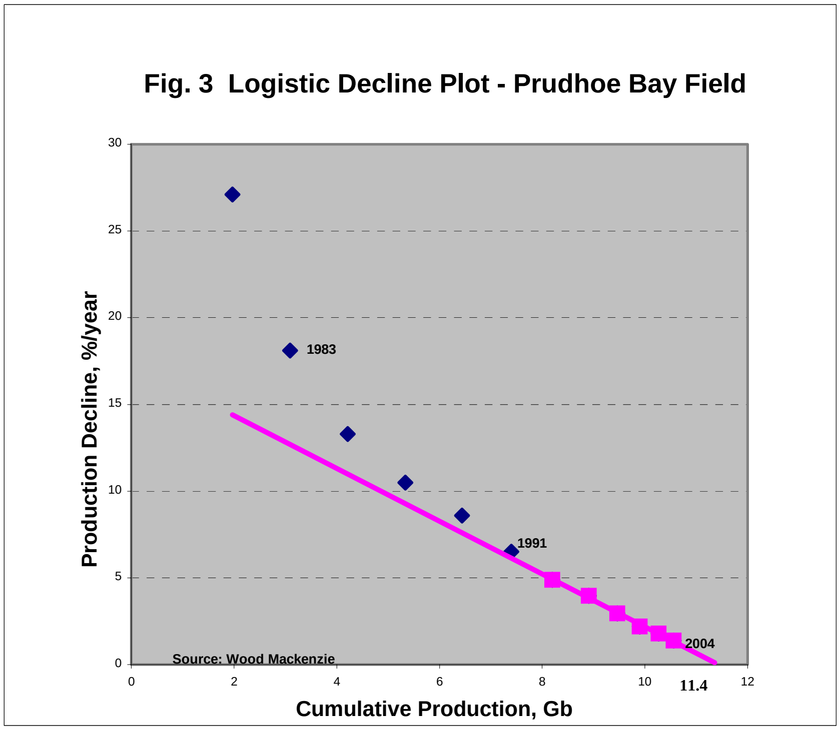
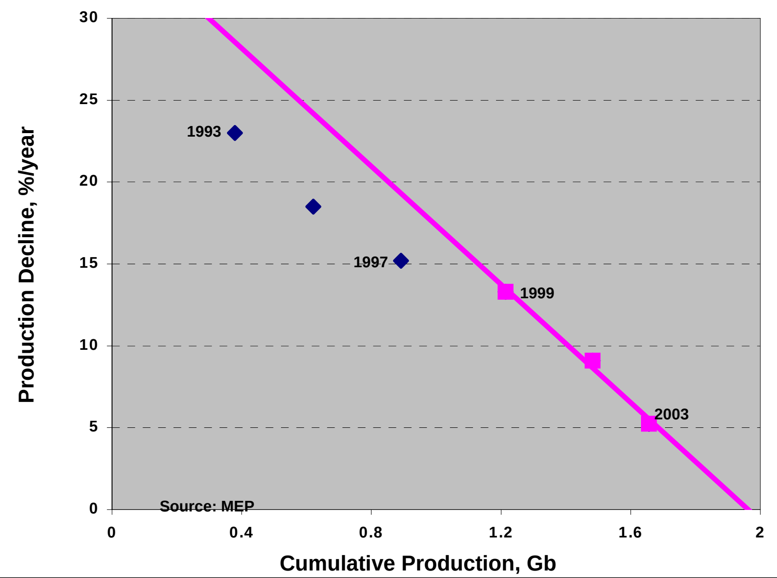


Fig. 3 Logistic Decline Plot - Prudhoe Bay Field
Production Decline, %/year
30
25
20
15
10
5
0
1983
1991
2004
Source: Wood Mackenzie
0
2
4
6
8
10
11.4
12
Cumulative Production, Gb

Fig. 4 Logistic Decline Plot - Furrial Field



11,5

Fig. 5 Logistic Decline Plot - USA

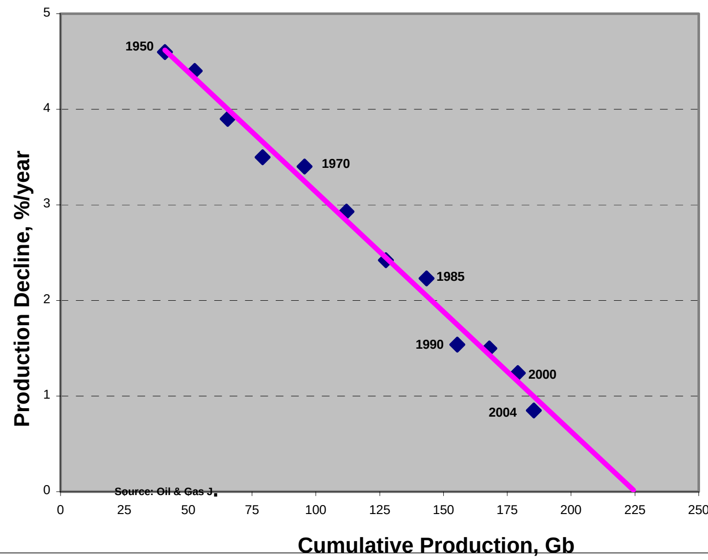
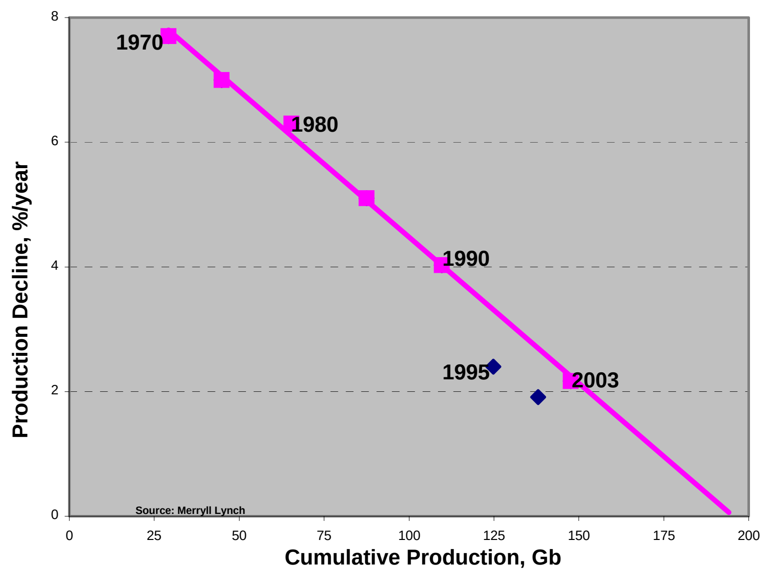


Fig. 6 Logistic Decline Plot - Russia



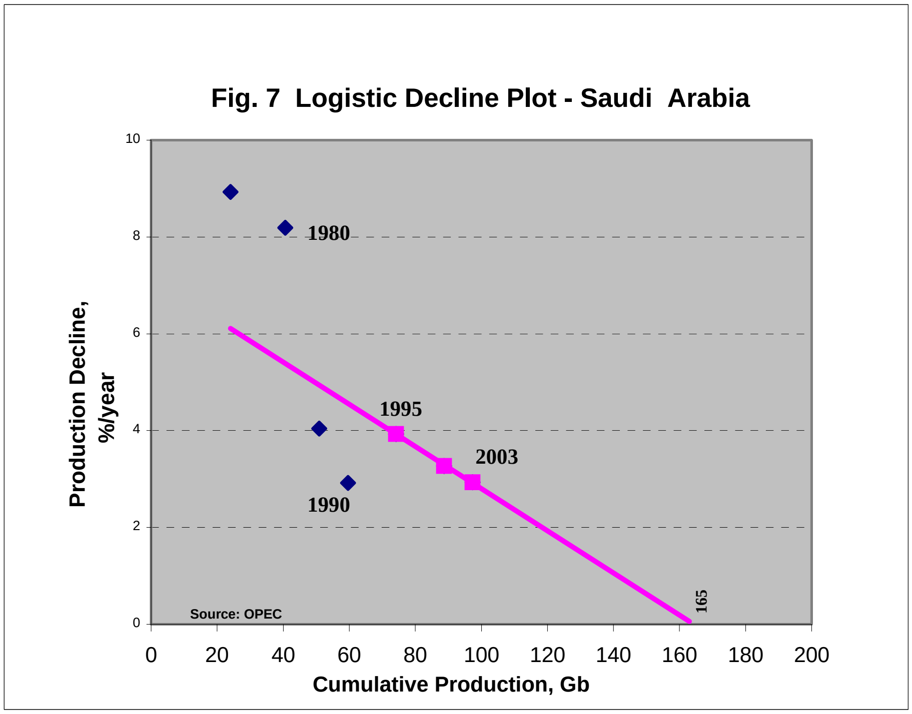


Fig. 7 Logistic Decline Plot - Saudi Arabia
Production Decline, %/year
Cumulative Production, Gb
1980
1995
2003
1990
165
Source: OPEC
0
2
4
6
8
10
0
20
40
60
80
100
120
140
160
180
200