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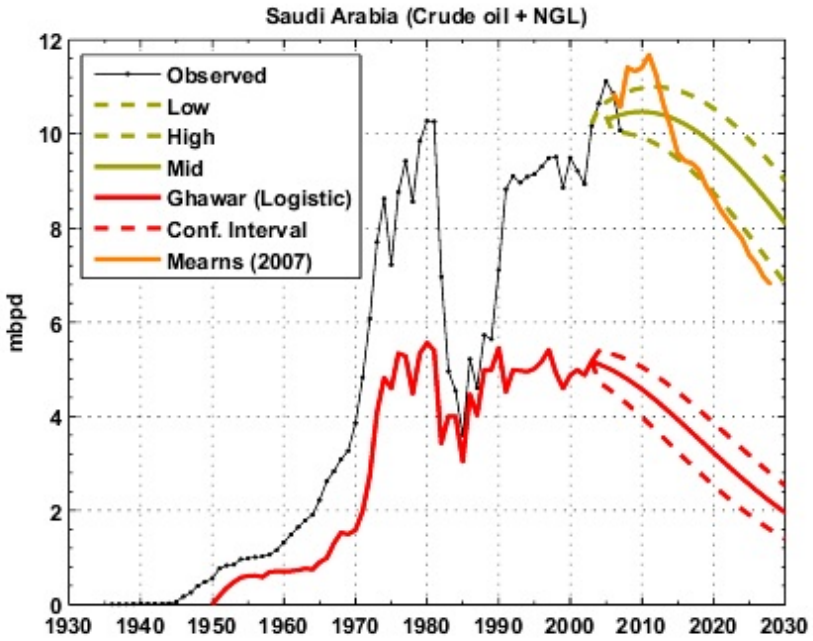
Saudi Arabia: An Attempt to Link Oil Discoveries, Proven Reserves and Production Data

Posted by Sam Foucher on January 3, 2008 - 10:32am
Topic: Supply/Production
Tags: saudi arabia, shock model [list all tags]

This article is an attempt to apply the Hybrid Shock Model (HSM) on Saudi Arabia's oil production. In a nutshell, the HSM is trying to model the observed production profile from the discovery curve by simulating the different phases involved in the development of oilfields (initial discovery, planning, build, maturity). The HSM is a variant of the Shock Model initially proposed by WebHubbleTelescope. One of the byproduct of the HSM is the instantaneous reserve addition (noted *R*). I based the following work on the assumption that the value for *R* should be somewhat close to available proven reserve figures. Of course, for Saudi Arabia available proven reserves are highly suspicious because of huge overnight reserve increase among OPEC members in the 80s without any new discoveries. Therefore, I will consider three increasingly conservative proven reserve hypothesis: 1) PR1: the official numbers as published by BP; 2) PR2: spurious increase are removed; 3) PR3: as proposed by Euan here, cumulative production is also removed. The volume of recoverable oil from Ghawar is then inferred from the HSM based on the discovery curve from IHS as the value that is minimizing the error between proven reserves and simulated reserve additions. My conclusions are the following:

1. No reasonable value for Ghawar size (i.e. < 150 Gb) is supporting the official proven reserve figure.
2. The most likely size for Ghawar is 109 ± 10 Gb and the simulated reserves are matching closely the corrected proven reserves (PR2).
3. Production capacity could reach a maximum around 10.5 ± 0.5 mbpd (crude oil + Natural Gas Liquids) between 2010 and 2013.



Discovery Data

Complete and accurate discovery data for Saudi Arabia is impossible to obtain. However, because Saudi Production is coming from a handful of giants and super-giants (Saudi Arabia has only about 80 oil fields), we can reconstruct a rough discovery dataset.

Field	Discovery Date	Production Start	(a)	(b)	(c)	(d)	(e)	(f)
Dammam	1938	1938	1.05	1.045	0.325		1.5	1.5
Abu Hadriyah	1940	1963	1.76	1.055			1.840	1.8
Abqaiq	1940	1946	12.8	12.5	5	13–19	12.8	15.0
Qatif	1945	1951	3.2	9	8.62		6.0	6.0
Ghawar	1948	1951	83	83	85	66 –150	82.0	105
Fadhili	1949	1964	0.95	0.96			1.0	
Safaniya-Khafji	1951	1957	32.3	22.5	41.16	21–55	36.1	27.23
Khursaniyah	1956	1965	2.3	4	3.33		4.1	4.1
Khurais	1957	1963	8.7	8.5	16.78	13–19	8.5	8.7
Manifa	1957	1964	17.1	11	22.79	11–23	17.0	17.1
Abu Safah	1963		7.81	6.6	6.15		7.5	7.85
Berri	1964	1967	7.3	12	14.94	10 –25	12.0	14.0
Zuluf	1965	1973	10.64	8.5	18.23	11–20	10.6	14.0

Fereidoon-Marjan	1966		10					
Marjan	1967			8	9.26		4.575	4.0
Janan	1967			0.5			0.5	
Karan	1967			0.01				
Shaybah	1968	1999	5.71	7	14-19.82	7–22	7.0	7.0
Barqan	1969		0.5				0.250	
Mazalij	1971		0.63	0.338			0.675	
Harmaliyah	1972		1.03	1.025	1.81		2.0	2.0
Abu Jiffan	1973		0.5	0.279			0.560	
Maharah	1973		1.1	0.5			0.5	1.1
Qirdi	1973			0.036				
El Haba	1973			0.057				
Rimthan	1974			1.3			0.6	
Lawnah	1975		1.17					
Dibdibah	1975			0.007				
Hawtah Trend	1989	1994			1.97			2.0

Table I. Size estimates for Saudi Arabia major oilfields (in Gb). Sources: (a) Colin Campbell's book "Golden Century of Oil 1950-2050", 1991, pages 296 & 341 (kindly provided by Ace); (b) Rand, 1975 (kindly provided by Ace); (c) Simmons, "Twilight in the Desert", 2005. (d) Robelius, 2006. (e) Carmalt and St-John, Giant Oil and Gas Fields (kindly provided by Phil Hart).; (f) Petroconsultants list of top 179 fields (thanks to Rembrandt Koppelaar).

The size estimates for the top 12 fields are shown on Figure 1.

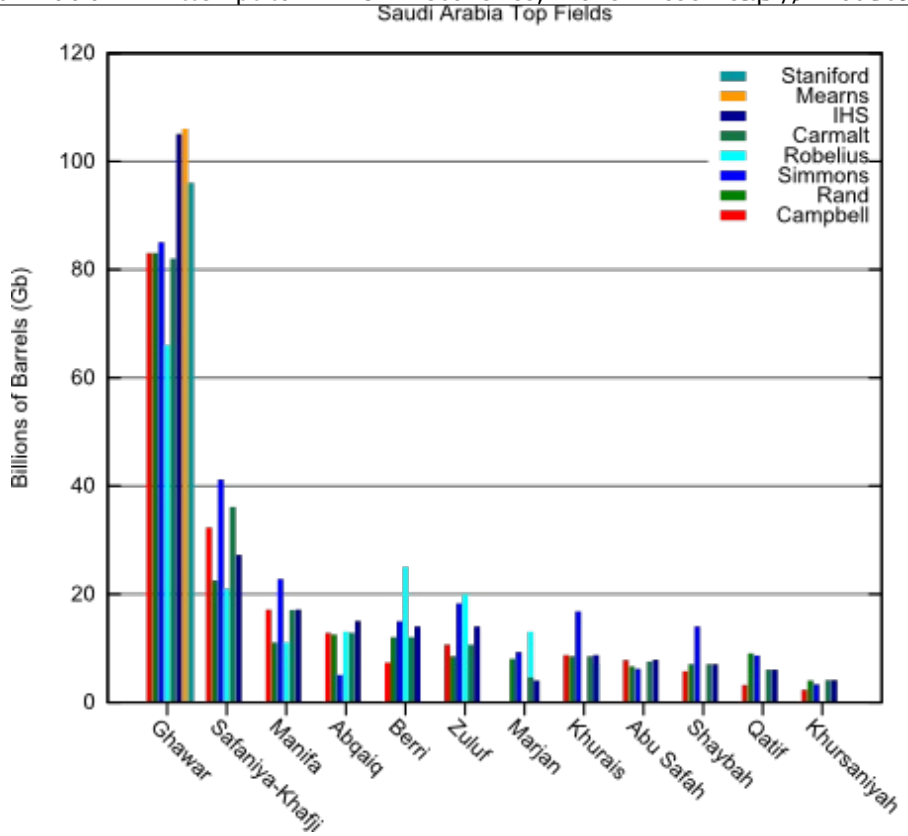


Fig 1. Saudi Arabia Top 12 fields. Click to view a SVG image.

In addition, I will use an oil discovery dataset presumably from IHS (believed to be for crude oil + condensate + NGL) and kindly provided by Rembrandt Koppelaar and shown on the figure below. Ghawar is 120 Gb and the total resource base is 309 Gb in 2005.

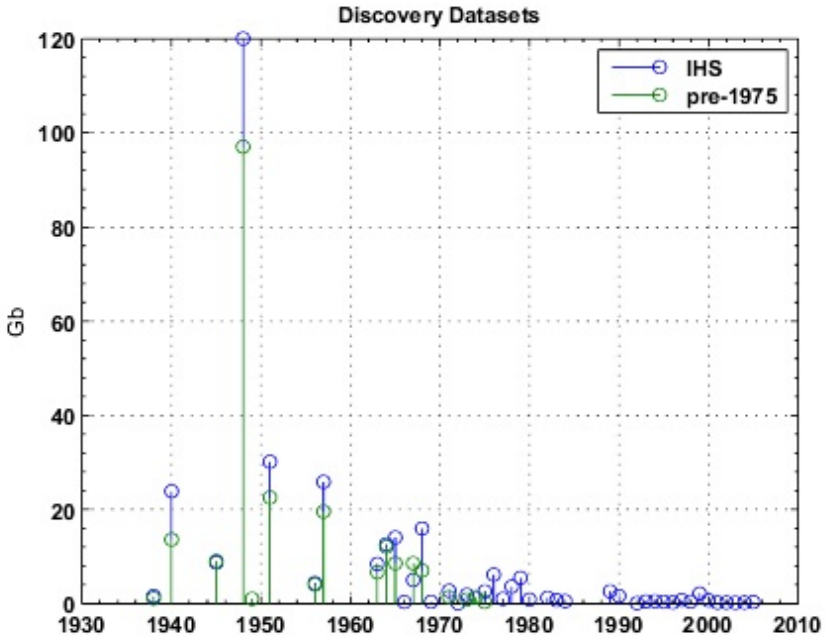


Fig 2. Discovery datasets for Saudi Arabia.

Proven Reserves

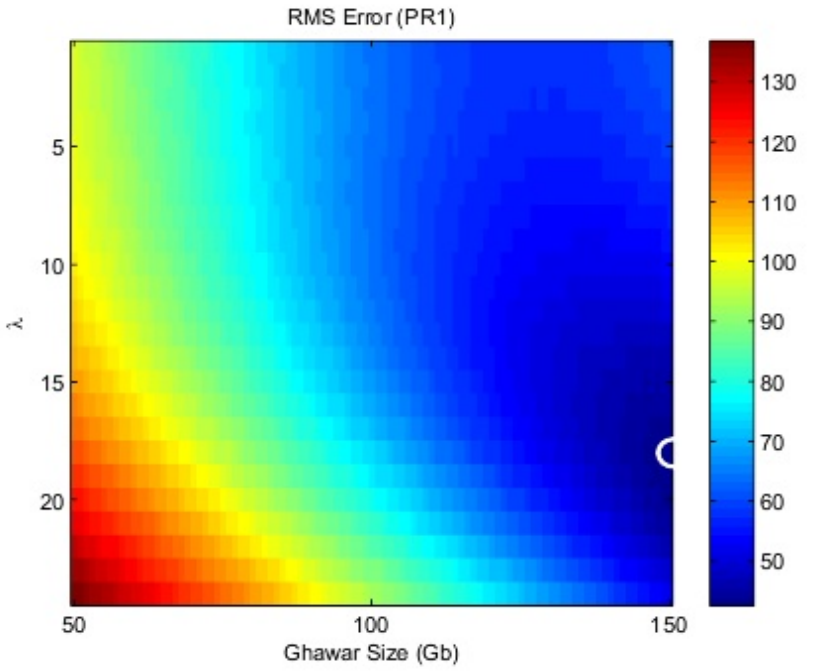
I will consider three cases for the proven reserves (a high case, a middle case and a low case):

1. **PR1**: Official proven reserves as published by BP in their annual statistical review.
2. **PR2**: Official proven reserves corrected for anomalous reserve increase ((i.e. mainly removing the 85.4 Gb increase in 1988).
3. **PR3**: Official proven reserves corrected for anomalous reserve increase and cumulative production as proposed by Euan here.

Model Inference

We are trying to answer the following question: What is the more likely value for Ghawar ultimate recoverable oil volume according to the Hybrid Shock Model? In order to answer that question, we will consider Ghawar size as a parameter of the model. The quality of the match between predicted reserves and actual reserve values under the different scenarios will be our measure of likelihood of our model parameters.

In addition to Ghawar size, the main parameter of the HSM is the λ parameter which is the sum of the three individual λ associated with each oil production cycle (i.e. $\lambda = \lambda_{build} + \lambda_{fallow} + \lambda_{mature}$). This parameter is controling the shift between the backdated discovery curve and the actual reserve additions ready to be produced (see blue and green curves on Figure 5). A small λ value means that new discoveries are immediately developped and new supply is coming online very rapidly. Conversly, a large value means that new discoveries are taking a long time to be brought online and reserve additions will be small and spread over a long period of time. For the case of Saudi Arabia, it is difficult to put a prior on λ values, we can expect a fairly large λ value because of the harsh environment and the size of the projects (e.g. Haradth development in three phases took nearly ten years (build phase) for a production capacity of 900 kbpd). Values for Ghawar size were taken between 50 and 150 Gb and λ between 1 and 24 years, it results in the following RMS surface:



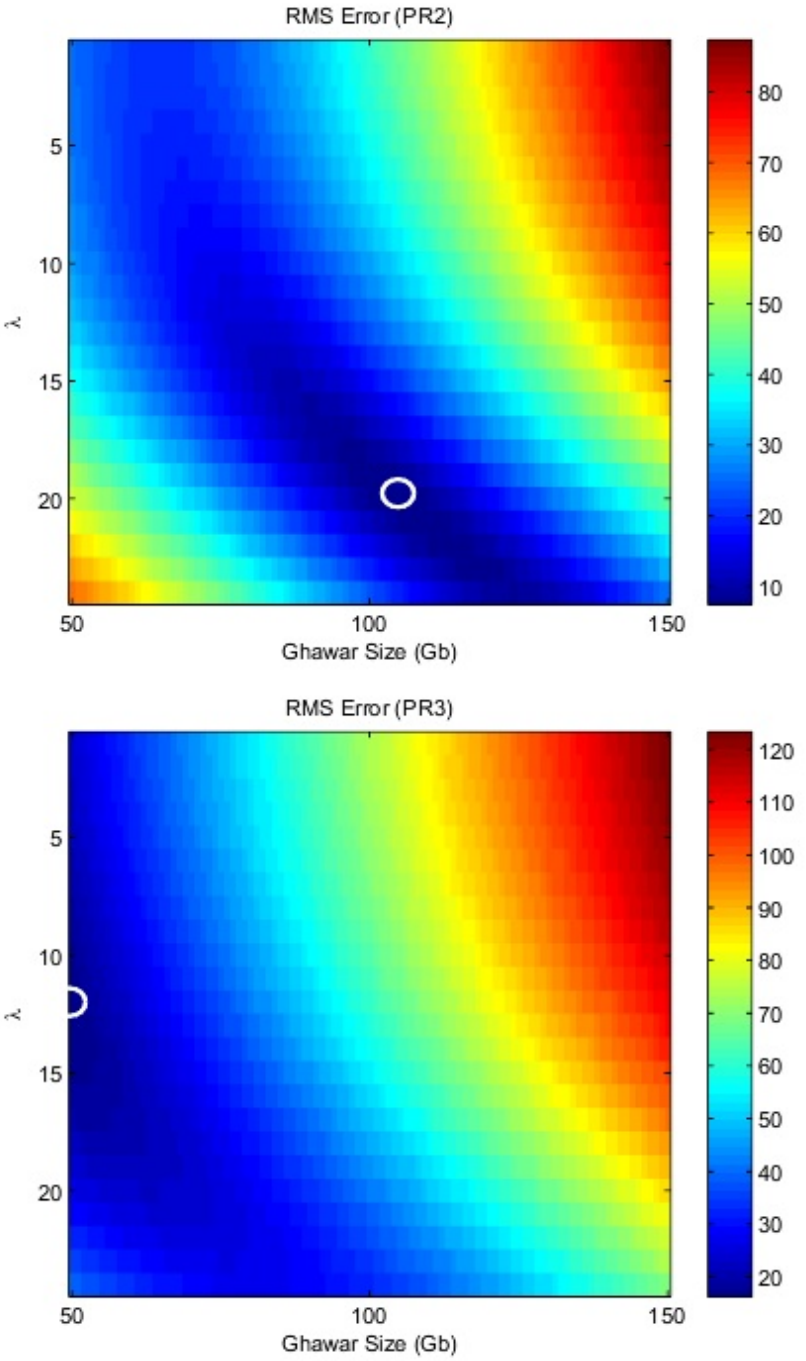


Fig 3. Minimum prediction error surfaces for reserve numbers as a function of Ghawar size and λ under the three proven reserve hypothesis considered.

We can observe a nice valley of low RMS values for PR2 and a minimum for $\lambda \approx 21$ years and Ghawar URR at 109 Gb. The error surfaces are further summarized on the chart below by taking the minimum error value along the λ axis. We can see that the PR2 hypothesis generates the smallest error values across all the parameter space. In order to reach the same error level, the PR1 hypothesis would require an impossibly high value for Ghawar (~200 Gb) and lambda (λ>40 years) and PR3 a very small value (~30 Gb) and λ~1 year. A confidence interval can be roughly estimated by taking the values corresponding to 90% of the minimum error which gives 109 ± 10 Gb.

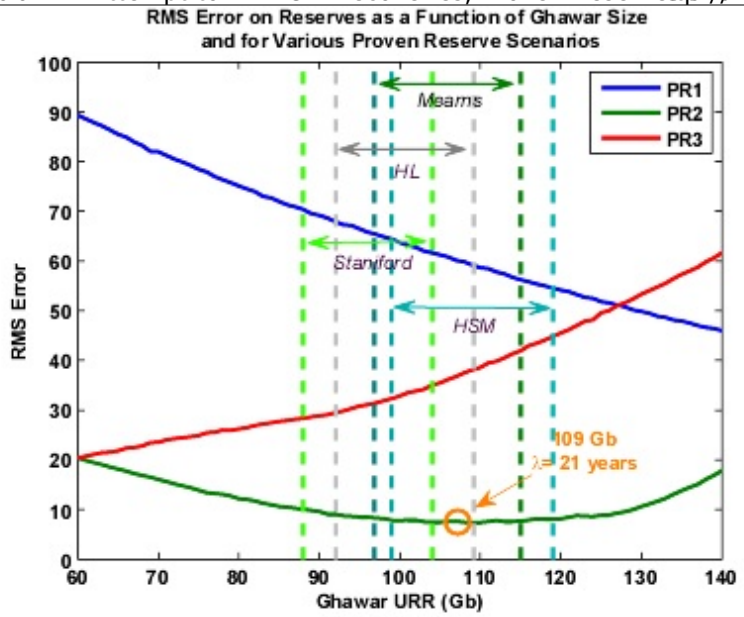
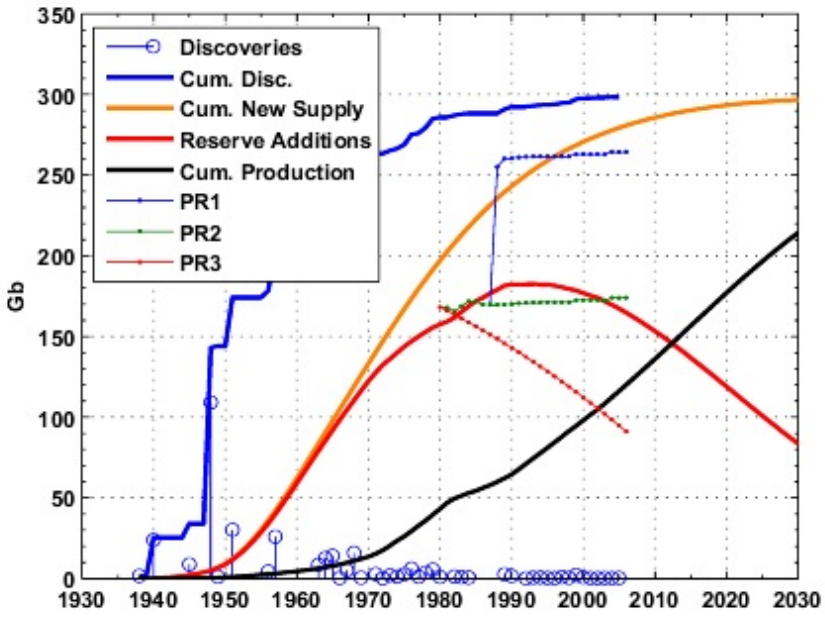


Fig 4. Minimum prediction error for the reserve values for each value of Ghawar size and different Proven Reserve scenarios. The minium error value is for Ghawar at 109 Gb and λ=21 years assuming the middle case (PR2) for the proven reserves. Various lower/upper bound estimates available are shown as vertical dotted lines. Click to Enlarge.

The corresponding HSM production capacity forecast is given on the Figure below and is fairly more optimistic than Euan's forecast for instance. The URR assuming no new discoveries is around 300 Gb (crude oil + NGL) and no decline in production capacity is seen before 2015.



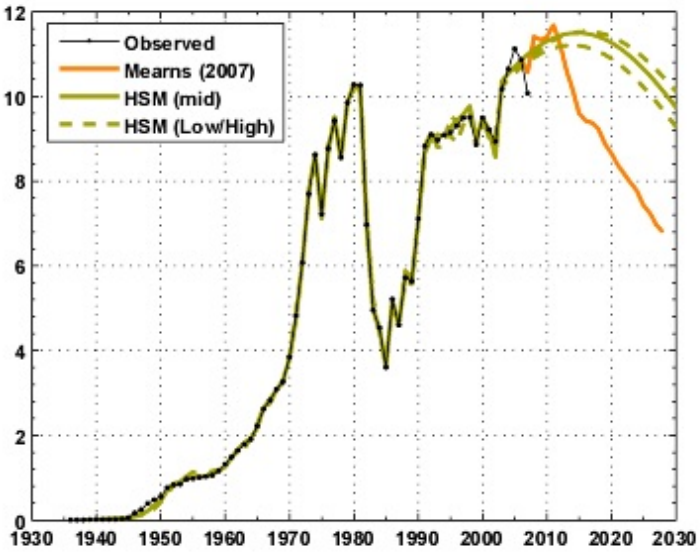


Fig 5. HSM output for Ghawar at 109 Gb and λ= 21 years. *Note the close match between simulated reserve additions (in red) and PR2 proven reserves (green dotted line). Euan Mearns's forecast is explained here.*

Modeling Non-Ghawar Production

Because Ghawar is such a dominant (and old) feature of Saudi Arabia production, I will model separately the contribution from Ghawar (as a logistic decline as explained in a previous post) and the contributions from the other fields. We can see on Figure 6, that the contribution from giant fields is overwhelming. and amounts to about 170 Gb of the 190 Gb of non Ghawar total discovery volume.

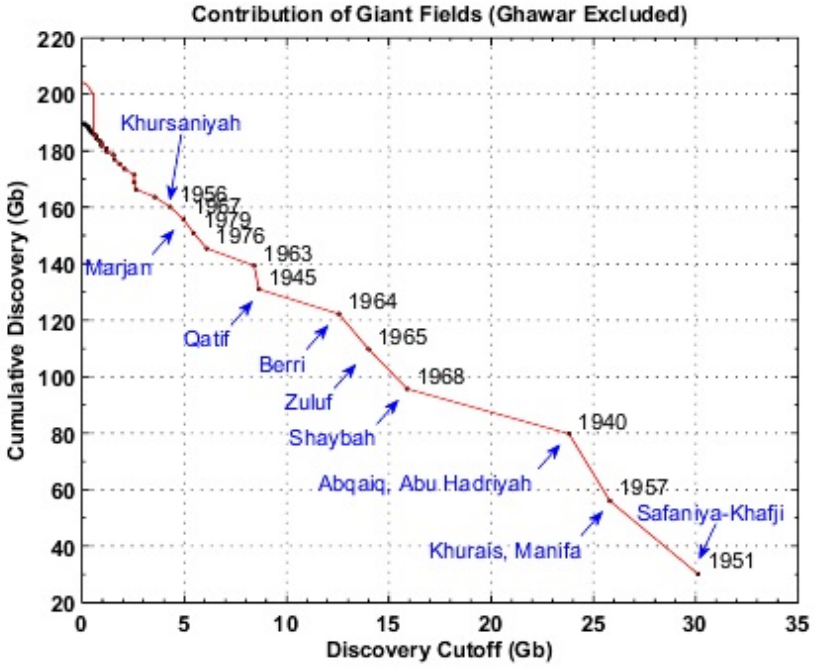


Fig 6. Saudi Arabia giant field contributions, the IHS discovery dataset is used and giant fields contributions are identified using their discovery date (see Table I).

It's obvious that not all the small discoveries will be developped. Therefore, in order to simulate the non Ghawar production, I considered two cutoff values for the discovery size: 1 Gb and 5 Gb.

This result in two different forecasts for the non Ghawar production (green and blue lines on Figure 7).

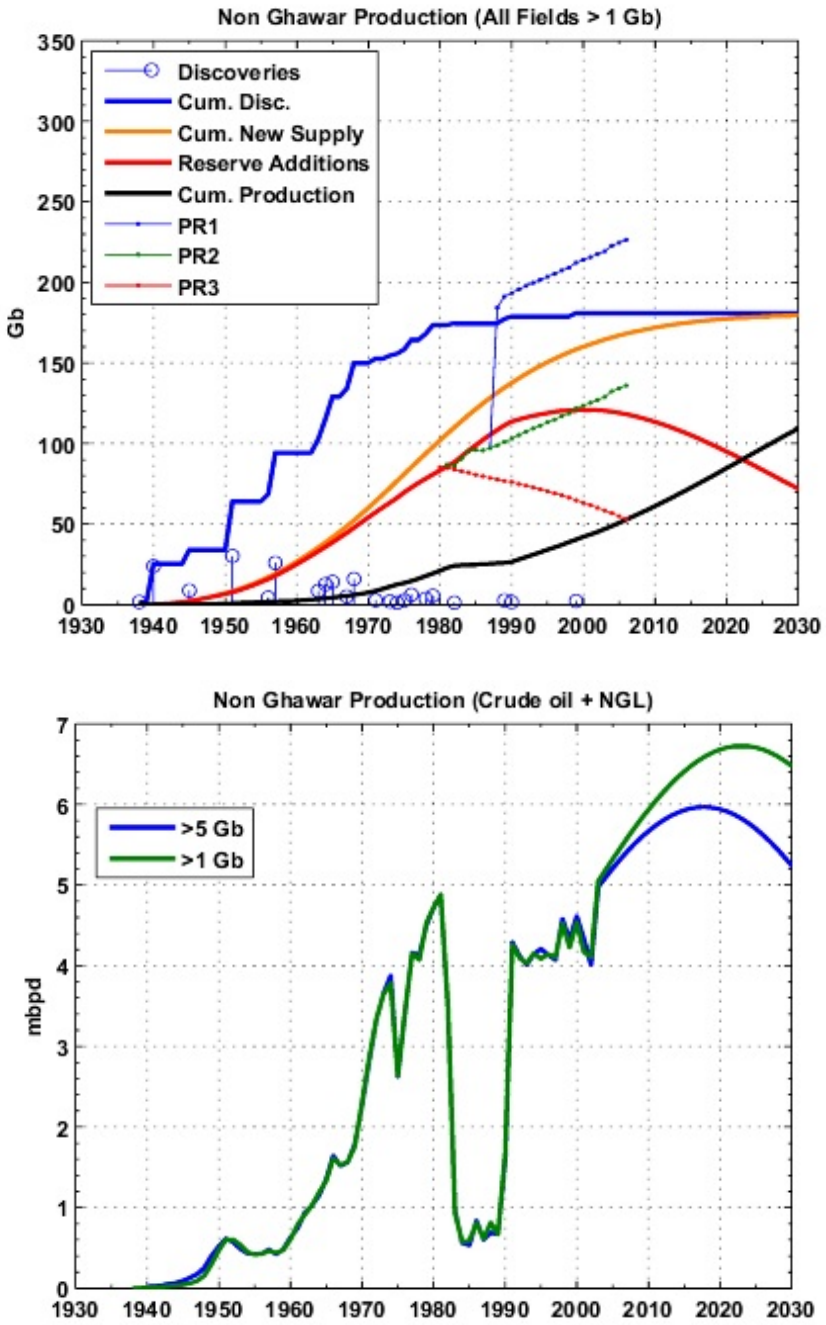


Fig 7. Discovery curve and various cumulative quantities from all the fields minus Ghawar given by the HSM (left or top) and the resulting production capacity forecast assuming a logistic model for Ghawar.

The result of the two stage modeling is shown on Figure 8 below (top or left chart). Compare to the previous result, we get almost a flat production line with a decline starting between 2010 and 2012.

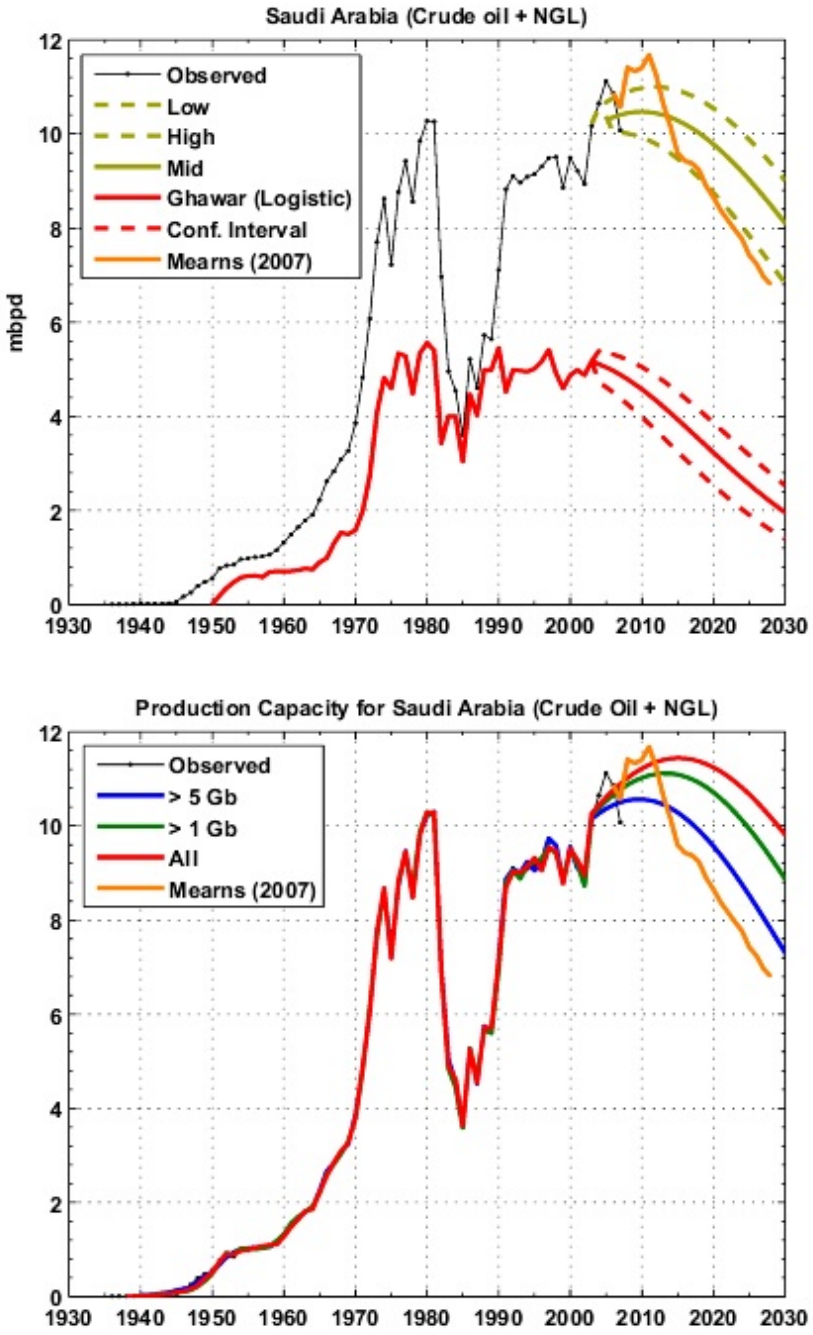


Fig 8. Ghawar-logisitc + HSM (left or top chart) and HSM on total production assuming different field size cutoff values (right or bottom chart).

What's left to be discovered?

Volumes of new discoveries have been anemic since the 80s and there is no reason to believe that this trend will change in the future despite speculations that significant fields are waiting under the empty quarter. I quote Rembdrandt:

> The USGS noted a potential of 136 billion barrels of conventional oil + NGL to be discovered between 1996 and 2030 in Saudi Arabia (9% of the total of 939 billion barrels). Between 1 January 1996 and 1 January 2006 approximately 5 billion barrels

> have been discovered in Saudi Arabia. Since the nationalisation in the '70s foreign companies could not drill in the country. Only since 2004 have several western oil companies have been allowed to drill for gas in the Rub Al Khali Region (empty quarter), which is positioned in the south and south/west.

Based on the IHS discovery profile for the years 1981 to 2005 and using a boostrap technique, we can expect the annual discovery rate to be between 0.32 and 0.81 Gb per year (95% confidence interval) which amounts to a total of 8-21 Gb of Yet-To-be-Find between 2006 and 2030.

In Summary

We proposed to apply the Hybrid Shock Model in order to retrieve the most likely Ghawar size value under different proven reserve scenarios:

1. The most likely range for Ghawar is 109 ± 10 Gb which is close to Euan Mearns's estimate.
2. Among the three proven reserve scenarios, the PR2 (i.e. corrected for spurious reserve jumps) is the most likely. The official proven reserves seem to imply that Ghawar is around 200 Gb with a very high value for the mean production lag time (λ>40 years).

The various Ghawar size estimates are shown on Figure 9 below. The median value is 98 Gb and the MAD estimator gives 22 Gb, consequently the 95% confidence interval is 76-120 Gb.

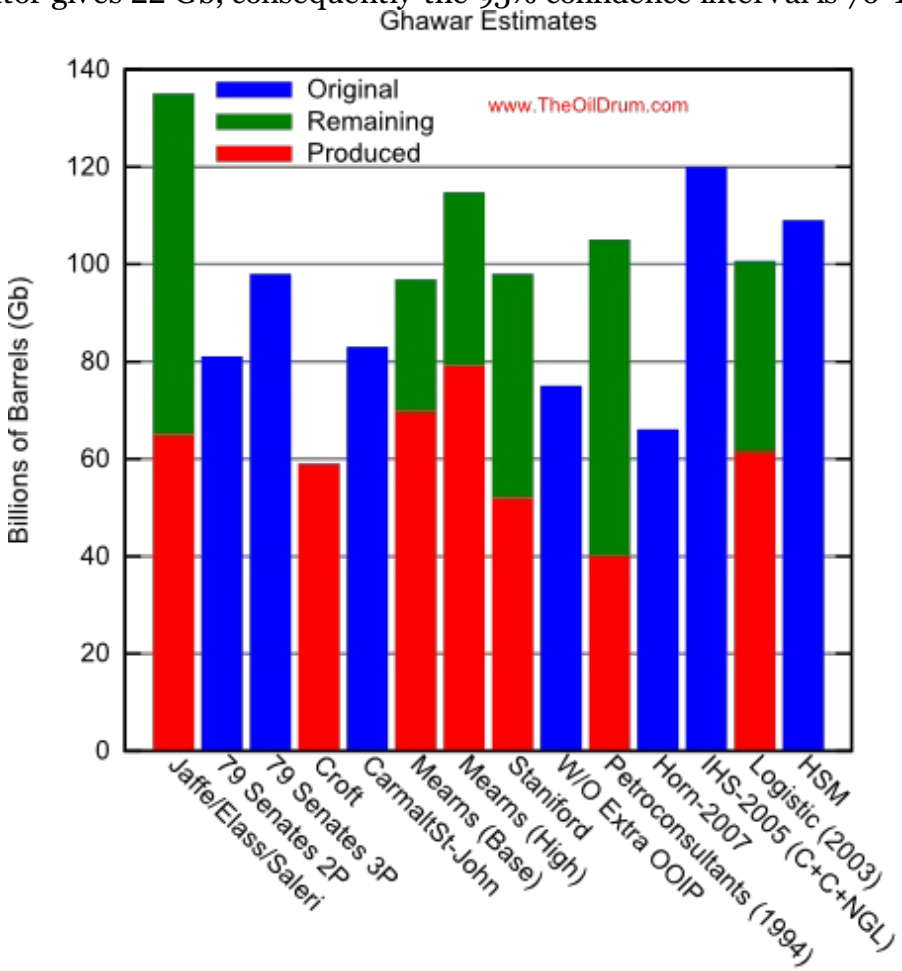


Fig 9. Summary of various forecasts for Ghawar (derived from Stuart Staniford's original compilation, details here). Click to view a SVG image.

The table below is summarizing the different results:

Proven Reserves	Ghawar size (Gb)	Non Ghawar resource base (Gb)	YTF (>2006)	URR (Gb)
PR1 (264 Gb)	~200	190	8-21	402
PR2 (174 Gb)	109 ± 10			313 ± 17
PR3 (91 Gb)	~30			232

The URR is forecasted to be around 313 Gb assuming that all the small fields will be developped (field size cutoff at 0). However, if we assume that only fields above 1 Gb will be developped, we get an effective URR around 290 Gb. The chart below is summarizing different forecasts (it is an updated version of Euan's chart). The HSM is a little bit higher than Campbell which is for crude oil + condensate (C+C) only.

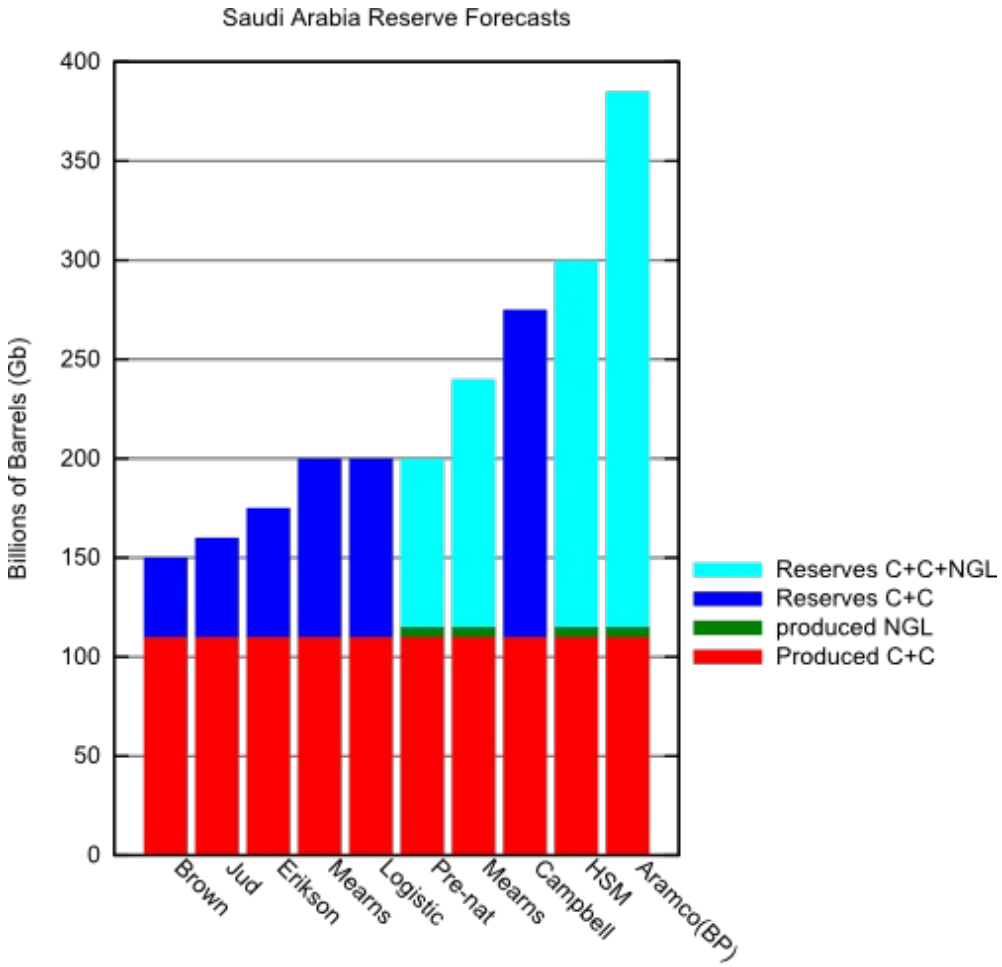


Fig 10. Summary of various forecasts for Saudi Arabia (derived from Euan Mearns's compilation). Click to view a SVG image.

The HSM applied on the total production (Figure 5) does not show any decline in production capacity before 2015-2016 with a maximum capacity at 11.5 ± 0.25 mbpd. The two stages production modeling where Ghawar is modeled separalely (Figure 8) is a little bit less optimistic and shows a decline in production between 2010 and 2013 with a maximum at 10.5 ± 0.5 mbpd. The model does not support claims that production capacity could go beyond 12-15 mbpd however it seems to indicate that production could be maintained around 10 mbpd for a long period of time. I find it intriguing that the HSM is confirming values derived from other

orthogonal methodologies and seems to put together nicely different pieces of the puzzle (i.e. Ghawar size, corrected proven reserves and Saudi Arabia discovery data). Note that an eventual reserve growth contribution has not been taken into account in this work.

Further articles about Saudi Arabia:

by Stuart Staniford

- Saudi Arabia and Gas Prices
- Depletion Levels in Ghawar
- The Status of North Ghawar
- Further Saudi Arabia Discussions
- Water in the Gas Tank
- A Nosedive Toward the Desert
- Saudi Arabian oil declines 8% in 2006

by Euan Mearns

- Saudi Arabia - production forecasts and reserves estimates
- Ghawar reserves update and revisions (1)
- GHAWAR: an estimate of remaining oil reserves and production decline (Part 2 - results)
- GHAWAR: an estimate of remaining oil reserves and production decline (Part 1 - background and methodology)
- Saudi production laid bare
- Saudi Arabia and that $1000 bet

by Heading Out

- Simple mathematics - The Saudi reserves, GOSPs and water injection
- Of Oil Supply trains and a thought on Ain Dar

by Ace

- World Oil Forecasts Including Saudi Arabia, Kuwait and the UAE - Update Oct 2007
- Updated World Oil Forecasts, including Saudi Arabia
- Saudi Arabia's Reserve "Depletion Rates" provide Strong Evidence to Support Total Reserves of 175 Gb with only 65 Gb Remaining
- Further Evidence of Saudi Arabia's Oil Production Decline

by Khebab:

- The Hubbert Linearization Applied on Ghawar
- An Attempt to Apply The Parabolic Fractal Law to Saudi Arabia

by Luis:

- A few more thoughts on Saudi and HL