A Primer on Reserve Growth - part 2 of 3

Posted by Rembrandt on December 26, 2006 - 11:05am in The Oil Drum: Europe
Topic: Supply/Production
Tags: iea, jean laherrère, peak oil, reserves growth, usgs [list all tags]

This post is the second part in a three piece series about the phenomenon of reserve growth in already found oil fields. Insight in future reserve growth, which is often attributed to advancement in technology, is crucial in determining the peak of conventional oil production. For those not familiar with reserve growth it would be best to read part 1 first:

1. General introduction to reserve growth, what can we learn from the worldwide recovery factor of conventional oil fields?

In this second part various scientific studies about reserve growth in the United States, the North Sea and Russia are analysed. The third part will look at the reliability of the estimate from the United States Geological Survey in their World Petroleum Assessment 2000 with respect to future reserve growth.

What can we tell from reserve growth in the United States?

The situation in the United States is quite unique in the world. The country shows the largest amount of reserve growth over time in the entire world. Soveral fields have grown ten to twenty times their original size. The cause of this huge resreve growth is the reporting practice of operators, which report proven reserves only:

> "In principle, US companies are expected to follow industry guidelines that define Proved (described as having "reasonable certainty" in the SEC rules) as having a 90% probability of occurrence, but in practice it appears that their estimates come closer to the Mode value. For the last 20 years, the amount of positive revisions reported by the US Department of Energy were double the negative values, meaning that the original estimates had a probability of around 66%. That is close to the Mode value, which in fact represents what the engineers consider the most likely.
>
> The huge "field growth" of the United States is clearly a reporting phenomenon, as only 6% of the additions over the past twenty years have come from new discoveries. The rest-of-the-world reports Proved & Probable estimates, because the industry has a greater need to know what the fields will actually deliver when they plan costly offshore facilities or pipelines to remote areas.
>
> It is worth discussing this critical issue in greater detail. The SEC rules were formulated long ago when most US production was onshore, and required that reserves for financial purposes were restricted to those being drained by a producing well.. Such onshore fields could be placed on production as soon as the first well was drilled, meaning that the reserves grew as the field was drilled up over time, in some cases tapping subsidiary reservoirs or new pools at greater or lesser depth or in the immediate vicinity. In some cases, infill drilling was also undertaken changing the reserve estimates.

> In the rest of the world, the reserves of a field are normally reported when production starts, the earlier estimates being held confidential by the company. Host governments take an interest to ensure that good oilfield practices are used to maximize recovery, and in some cases revenue. The companies accordingly have to compromise in their reporting between their general desire to under-report and the demands of the host government. For these reasons, more valid estimates are reported, although still often as much as half what the field is eventually found to deliver."(J. Laherrère, 2000)

Because US operators are obliged to report very conservative proven reserves, a huge amount of reserve growth occurs. This makes it very difficult to estimate whether reserve growth is due to technological advancement or not. It is important to know that the Energy Information Administration makes an excellent division between added contributions from new discoveries, field extensions, new reservoirs discovered in old fields and changes in the reserve estimates of a given oil field. This makes it possible to exclude the contribution from added Oil Initially in Place in estimating Reserve Growth of the United States.

One of the main studies on reserve growth in the U.S. has been done by Attanasi and Root (The enigma of oil and gas field growth, AAPG Bulletin, 1994). The authors show that in the United States reserve growth keeps occuring, even in very old basins, based on proven reserves data from the Energy Information administration. The chart below shows the data from the article divided between oil discoveries per decade. It is clearly visible that most oil in the U.S. has been discovered in the '30s. The data from Attanasi and Root shows that reserves grew with 26 billion barrels between 1977 and 1991. More recent data from the Energy Information Administration shows reserve growth of 22 billion barrels between 1977 and 1991 and 10 billion barrels between 1991 and 2005.

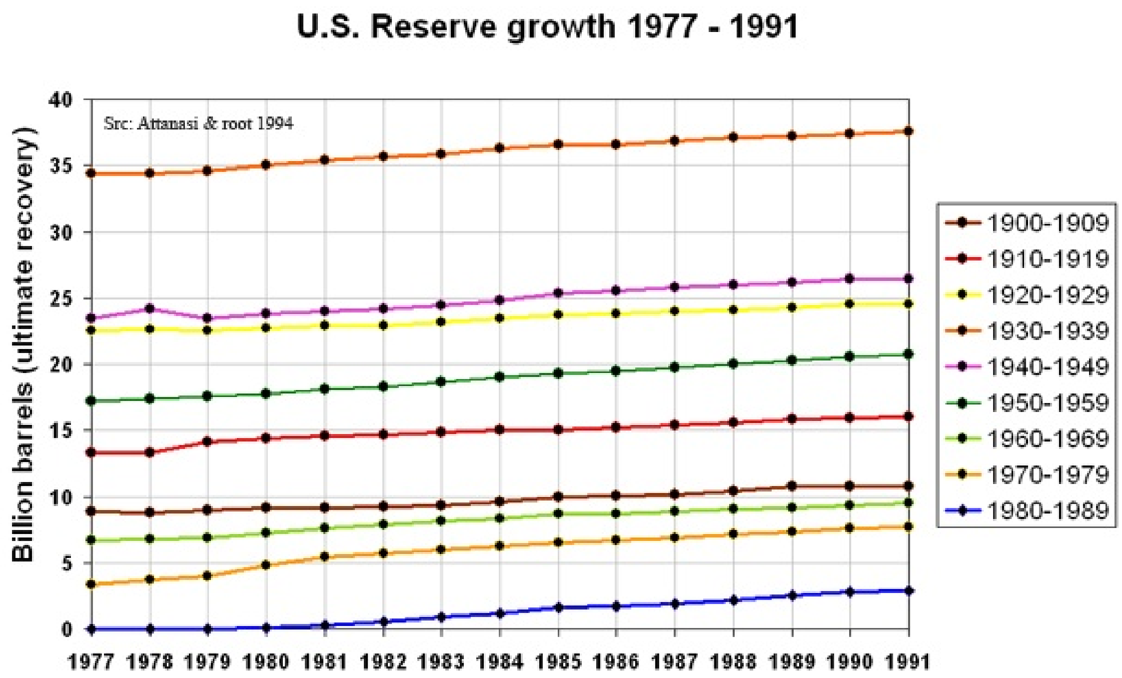

Chart 1 - Source: Attanasi & Root, 1994. Reserve growth shown over time, dividede between discovery years. Data series 1900-1909 shows reserve growth in fields discovered between 1900-1909 in the years from 1977 to 1991

Thanks to the excellent division from the EIA between reserve growth caused by growth in the Oil Initially In Place (OIIP) and growth in estimates for recoverable reserves, growth in OIIP can be canceled out from estimated reserve growth increases. However, it is impossible to tell based on the data to what extent reserve growth is caused by operator underestimates of recoverable reserves due to the practice of proven reserves reporting or due to technological advancement caused the growth in reserves. Nonetheless, the USGS concludes that technological advancement is the main driver in case of the U.S.:

> "After 90 years of production, reserves continue to grow for both oil and gas. As part of their study, attanasi and Root (1994)... Although the reserve growth in common fields, as shown above, is attributed primarily to water flood as well as to other EOR techniques [enhanced oil recovery techniques], it is not large enough to offset the decline in the remaining proved oil resreves caused by the ongoing production from the existing fields....The application of EOR techniques has occured in only a limied numbers of fields to date. Therefore, there is potential for additional resreves if EOR techniques are extended to other fields. " (USGS, 2000)

By analysing single field cases better comprehension of the influence of technology on reserve growth can be gained. Jean Laherrère has done analysis on several single fields in the U.S. and the North Sea. By plotting cumulative production versus annual production a reliable estimate can be made of the ultimate oil recovery of the field. Several of his examples are shown below:

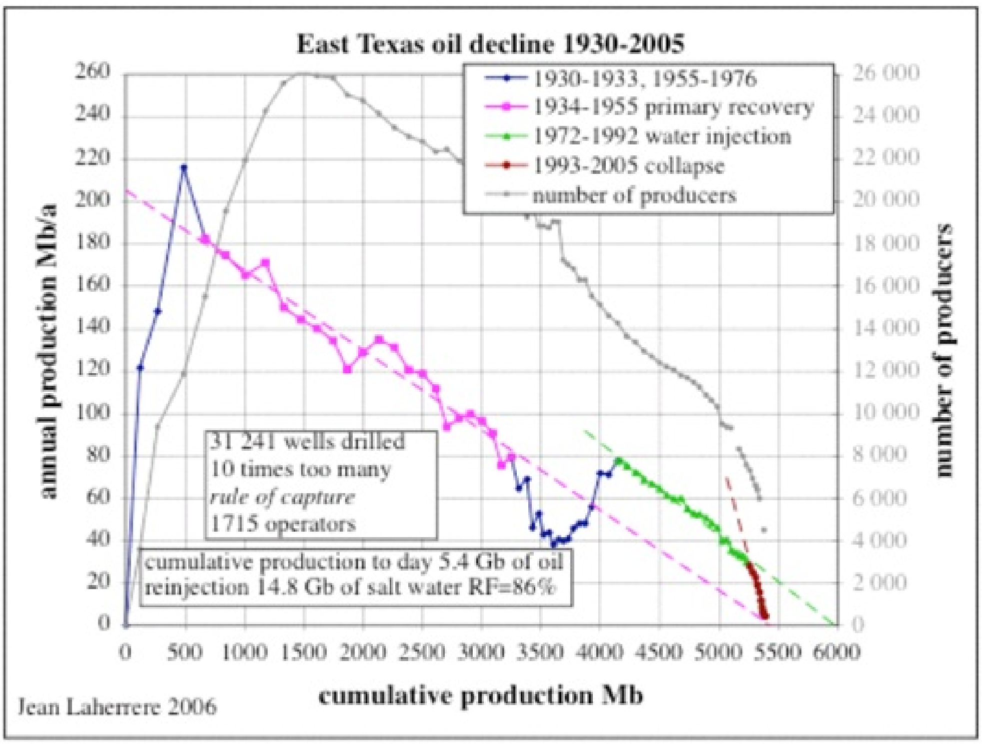

Chart 2 - Source: J. Laherrère.

East Texas is the largest oilfield in Texas with an API of 37 degrees and 0.21% sufur content. Production started in 1930, a water injection program began at the end of the '60s. Due to the water injection program east texas ultimate recovery of reserves (URR) estimate was changed to 6 billion barrels. This URR was held between 1975 and 1991. The URR changed back to the old estimate of 5.4 billion barrels in 1992 due to a sharp increase in the decline rate towards 10%, leading to an ultimate production value of 5.4 billion barrels. No increase in the recovery rate is apparent in the later life of this oil field, one of the largest in the U.S.

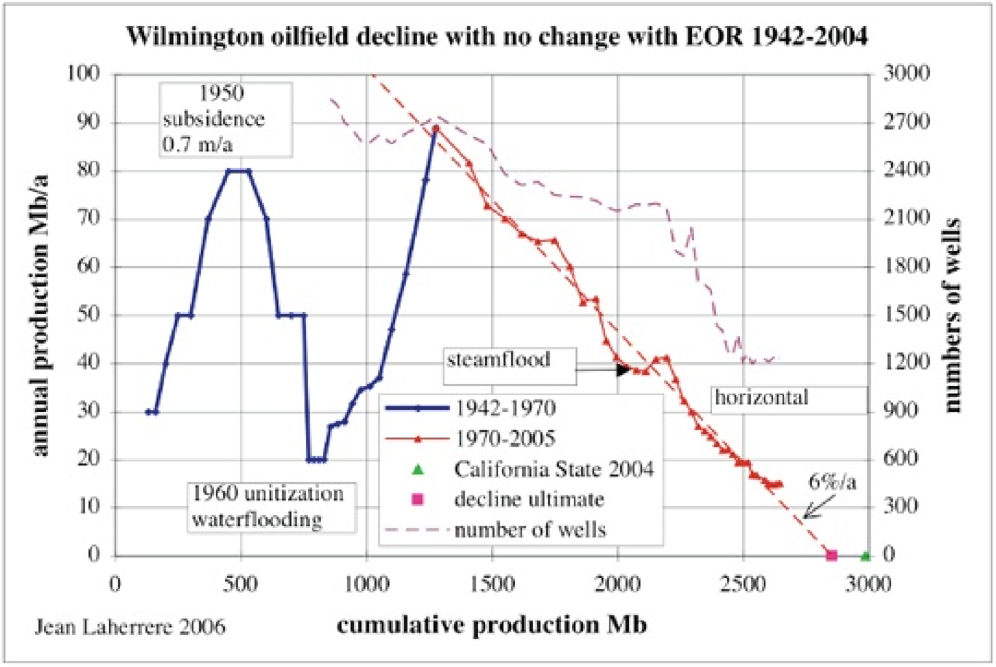

Chart 3 - Source: J. Laherrère.

Wilmington is an oil field discovered in 1932 in the Los Angeles Basin in southern California with an API between 13 and 25 degrees. In 1965 a Waterflooding program started. Due to subsidence (a downward shift of the surface), the reservoir became unitised which caused a large increase in the production level, peaking in 1970. The ultimate recovery of reserves (URR) estimate was increased due to this change from 1.2 billion barrels to 2.5 billion barrels. This estimate slowly increased towards 3 billion barrels in 2002. In a 2002 annual AAPG publication it was noted that an optimized waterflooding program and the application of horizontal wells had lead to a significant increase in proven reserves. Jean Laherrère noted however that an Ultimate of 2.8 billion barrels could already have been established in 1972. His observation leads to the conclusion that neither horizontal wells nor steamflooding did increase the reserves of the oil field. Reserve growth occured due to the natural change in the geology of the reservoir.

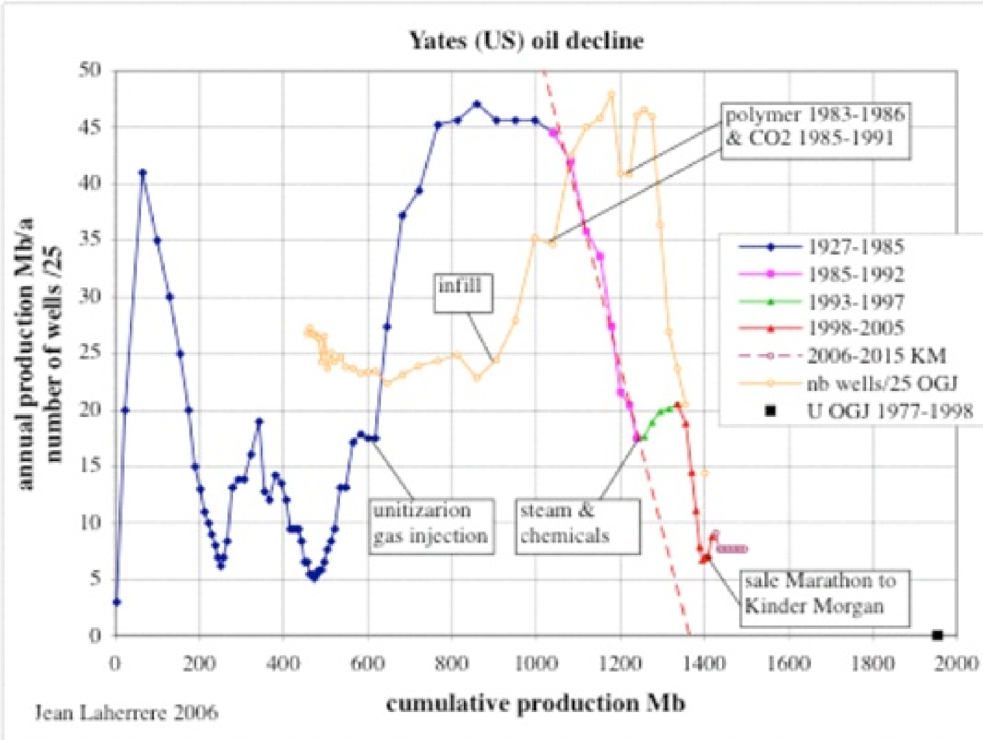

Chart 4 - Source: J. Laherrère.

Yates is an oil field discovered in the 1920's in Texas with an API of 30 degrees. After a gas injection program began, oil production sharply increased from 1975 to 1979. In 1984 production started to drop after a sharp plateau and continued to drop despite a Polymer flooding and a CO2 injection program. Between 1993 and 1997 production slightly increased for a few years due to a steam & chemical flooding program, soon after this program decline started again. The ultimate production will probably be 1.6 billion barrels. Enhanced oil recovery programs appears to have slightly increased the recoverable reserves of this field.

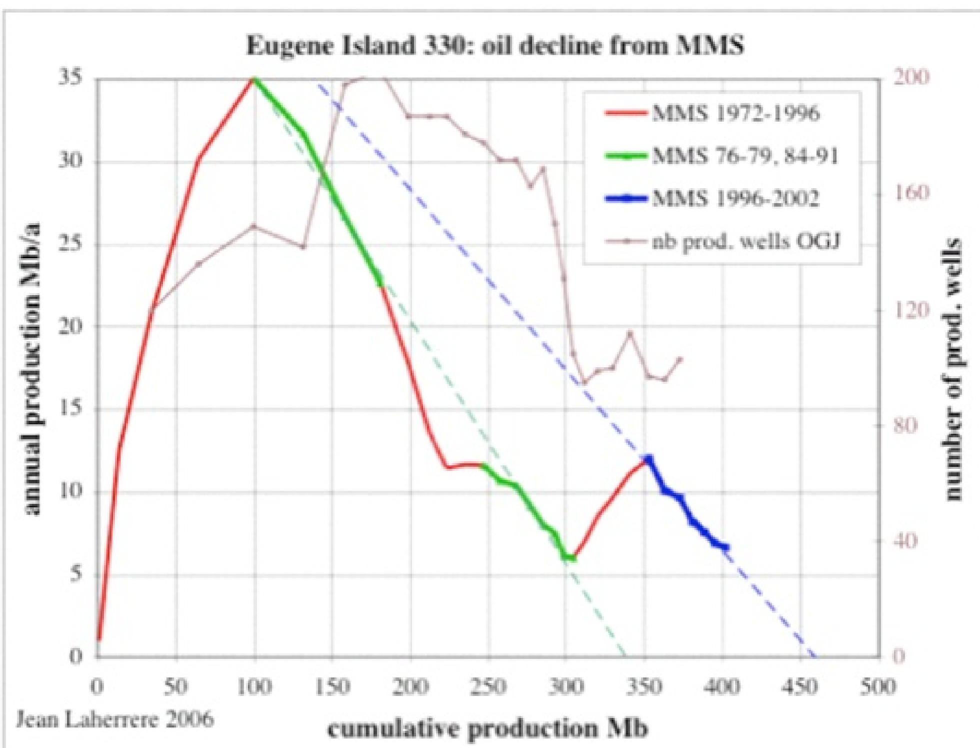

Chart 5 - Source: J. Laherrère.

Eugene Island is an oil field in the gulf of mexico discovered in 1971 with an API between 23 and 35 degrees. The field has an expectional structure with one of the largest faults (planar rock fractures, which show evidence of relative movement). This large fault (the red fault) allowed the reservoir to fill rather quickly from the source rock after pressure dropped 24 years from initial production. This exceptional structure caused a significant increase in reserves by reserve growth. Technological advancement does not seem to play a large role here. Details about the reservoir can be found in an article published in an AAPG journal available online.

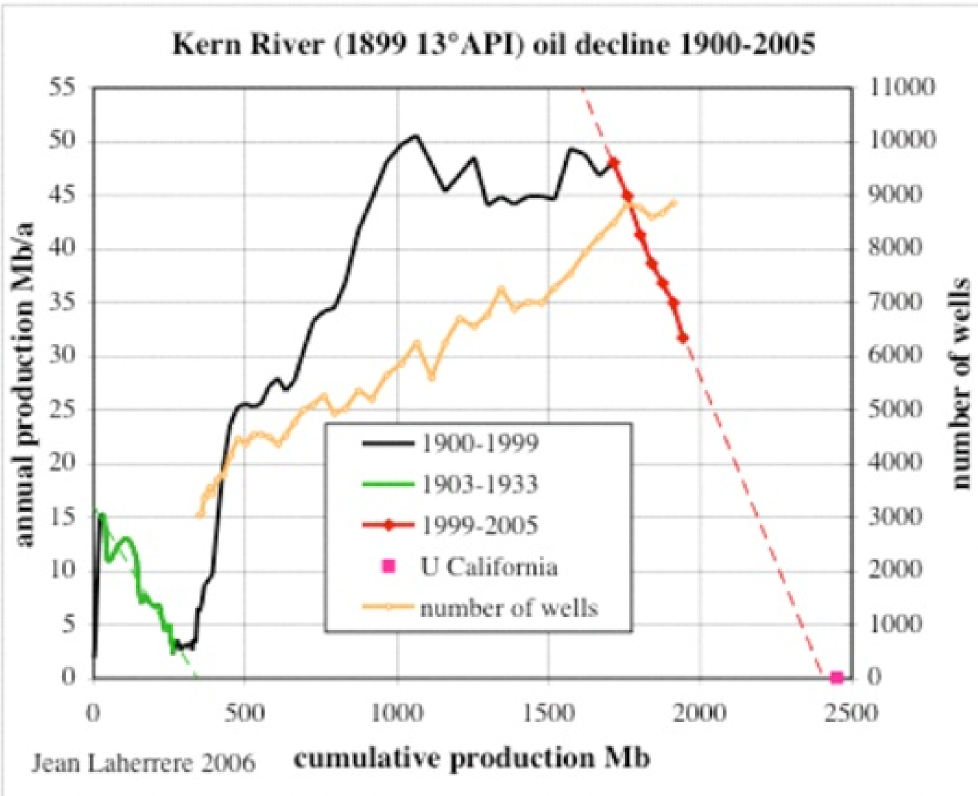

Chart 6 - Source: J. Laherrère.

Kern river is an oil field in california discovered in 1889 with an API of 13 degrees. An interesting detail is that the field was discovered by a hand dug hole. A nice graph showing the fields history is also available online. Production of this heavy oil field was first managed by conventional techniques. After 25 years production started to decline towards nearly zero in 1950. In 1961 water injection tests began in the reservoir, causing a slow by steady increase in production. Quite soon a steam injection program is started which helped to increase the production of the field once more, topping at 140.000 barrels per day in 1980. Finally in 1999 the fields production starts to decline again. This example shows that in unconventional heavy reservoirs the application of steam injection helped to increase the reserves of the field.

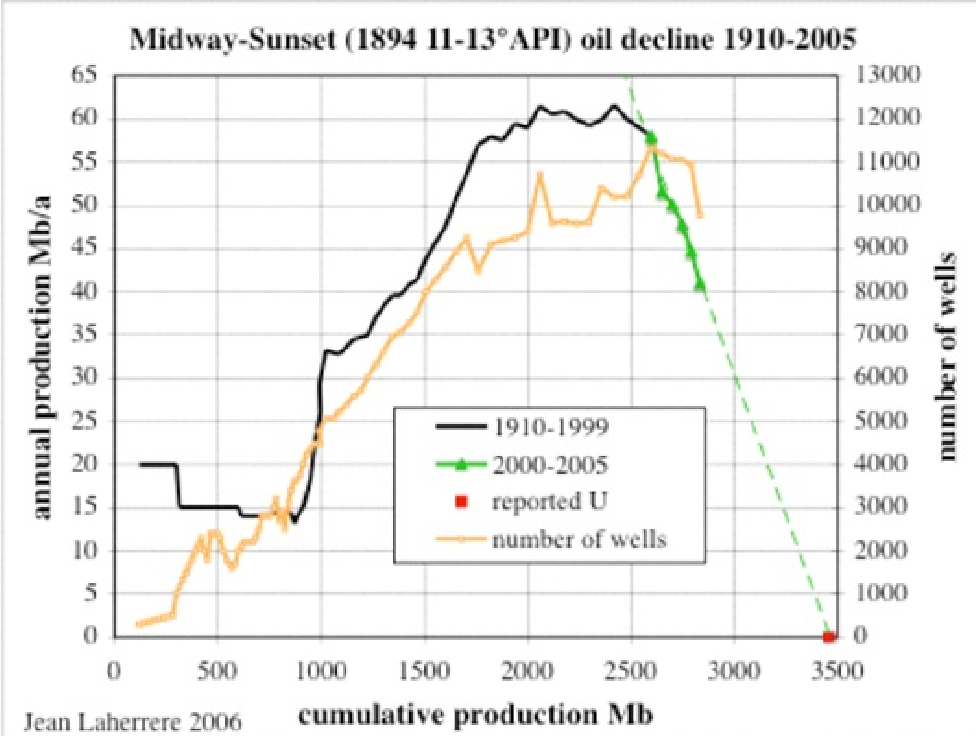

Chart 7 - Source: J. Laherrère.

Midway Sunset is an oil field in california discovered in 1893 with an API of 13 degrees. The field shows the same pattern as in the Kern river oil field described above.

Based on the figures and examples that are available with respect to the United States it is not so easy to reach a very clear conclusion on this oil producing region of the world. A large amount of reserve growth in the United has occured due to the practice of reporting proven reserves only. While reserve growth does occur due to technological advancement this seems to be mainly in unconventional oil fields. Several of these fields are also in the case of the U.S. added to the conventional oil reserve pool, and as such used in forecasting reserve growth for conventional oil reserves in the entire world by the USGS. This likely leads to too optimistic estimates with respect to reserve growth for the entire world.

What can we tell from reserve growth in Russia?

In June 2003 a study was published in the Natural Resource Research journal called: [Reserve growth in Oil fields of West Siberian Basin, Russia by Mahendra K. Verma and Gregory F. Ulmishek of the United States Geological Survey.]()

This study compares reserve growth in the following 42 large oil fields in the West Siberian Basin:

Table 1. List of 42 Fields from West Siberia that have Adequate Data for Reserve Growth Analysis

Agan	Orekovo-Yermakov	Vakh
Bakhilov	Pogranichnoe	Van Egan
Bystrin	Pokachev	Var Egan
Druzhnoe	Pokamasov	Vat Egan
Fedorov	Povkhov	Vatin
Khokhryakov	Pravdin	Verhne-Kolik-Egan
Kholmogor	Priob	Yaunlor
Lokosov	Prirazlomnoe	Yuzhno-Balyk
Lyantor	Samotlor	Yuzhno-Pokachev
Malo-Balyk	Severo-Khokhryakov	Yuzhno-Surgut
Mamontov	Severo-Pokur	Yuzhno-Yagun
Megion	Severo-Varegan	Zapadno-Surgut
Mortymya-Teterev	Ugut	
Nivagal	Ust-Balyk	
Novopokur	Vachim	

Chart 8 - Source: Verma & Ulmishek.

The study shows the change shown in the chart below for reserves in two categories, after the discovery year and after producion starts. These categories are divided between four different field sets of the 42 fields.

Reserve Growth in Oil Fields of West Siberian Basin, Russia 111

Table 2. Summary of Total Reserves (in Millions of Barrels) for Individual Sets of Fields Since Either the Discovery Year or the First Production Year for the West Siberian Oilfields (Total Reserve is the Sum of Cumulative Production and A + B + C_1 Category of Reserves.)

Years since discovery/first prod.	Total reserves in million barrels since discovery year for individual set					Total reserves in million barrels since first production for individual set			
	42 Fields	37 Fields	32 Fields	24 Fields	14 Fields	42 Fields	30 Fields	23 Fields	9 Fields
0	6,888.1	5,904.0	5,240.2	3,993.2	3,113.4	48,027.1	37,574.2	30,797.8	17,038.2
1	17,381.0	14,091.0	12,464.3	9,557.1	7,268.6	59,878.4	48,082.6	40,136.7	23,271.0
2	26,964.3	22,093.5	19,400.3	15,708.4	11,694.4	64,741.8	51,976.9	43,537.9	25,736.9
3	38,057.6	32,005.1	28,748.7	24,124.8	16,588.5	70,552.8	57,467.0	48,830.3	29,429.5
4	47,643.6	39,804.4	35,756.7	30,249.4	20,380.0	74,604.6	60,761.4	52,112.6	32,529.2
5	55,637.8	47,652.5	43,270.0	37,345.5	25,785.3	77,294.4	63,581.4	54,963.9	33,760.0
6	61,385.6	53,217.6	48,561.3	42,229.3	28,605.7	76,849.3	62,880.3	55,142.9	34,140.7
7	68,788.5	60,056.8	55,524.8	48,873.9	32,049.8	77,530.0	63,493.5	55,828.3	34,358.7
8	72,857.9	63,905.4	59,151.0	52,122.2	35,093.6	75,459.0	61,391.2	53,664.9	32,204.4
9	76,488.6	67,500.4	62,930.2	55,491.6	36,338.8	76,076.8	61,626.3	54,312.7	32,812.1
10	76,512.0	67,523.8	63,082.1	55,854.5	36,895.2		61,950.7	54,637.5	32,946.9
11	77,058.9	68,003.7	63,455.7	55,998.1	37,253.6		64,951.7	57,644.6	35,768.8
12		65,390.1	60,797.3	53,762.9	34,853.6		65,499.6	58,962.8	37,094.5
13		66,157.7	61,564.9	54,262.2	35,194.4		65,419.3	59,455.5	37,153.5
14		66,788.1	61,844.8	54,405.5	35,341.8		65,614.5	59,599.3	37,257.3
15		68,578.0	64,435.1	57,307.1	38,194.6			58,461.1	37,537.1
16			65,046.1	57,807.7	38,654.5			58,042.2	37,496.8
17			65,027.2	57,765.5	38,786.4			58,058.5	37,451.9
18			66,561.4	59,264.7	38,930.9			58,707.5	38,804.6
19			66,883.2	59,586.1	39,117.5			58,601.1	38,880.5
20			65,017.2	58,587.2	39,243.1				39,215.0
21				57,078.1	39,292.5				39,322.5
22				58,221.0	40,734.0				39,554.7
23				58,714.8	41,161.4				38,251.1
24				59,420.4	41,610.3				37,888.6
25				59,572.4	41,656.3				37,607.7
26					41,264.0				
27					41,442.0				
28					41,763.9				
29					41,778.5				
30					41,918.9				
31					42,462.3				
32					42,853.0				

Chart 9 - Source: Verma & Ulmishek.

What can be observed is that reserve growth mainly occurs in the first six years after initial discovery. The most likely explanation is an underestimate of initial reserves. Furthermore very little to no reserve growth occurs in later stages of the fields production, supporting the idea that technology does not influence reserves. The authors of the study conclude:

> "All the models show rapid reserve growth in the first five years, though to different levels, but the West Siberian models show gentler growth in the following years. Slower growth in West Siberian fields is caused by different reserve booking requirements and **probably** by insufficient investment in improved production technologies."

In a latter reference to this study the main author, Verma conclude that based on this study and assessments from the US that:

> "Field growth occurs in almost all petroleum provinces of the world primarily due to the advancement of technology in various aspects of petroleum exploration and development."

Several doubtful claims about technology are lifted towards reality by the USGS, which are not supported by their own studies. Reserve growth data from Russia does not support the idea that the advancement of technology causes reserve growth in conventional oil fields.

What can we tell from reserve growth in the North Sea?

The North sea is very interesting because the historic data for the United Kingdom and Norway vary wildly with respect to reserve growth. At the same time, both regions have excellent (but different) reporting practices. An early study from MIT (1997) showed large reserve growth in Norway and small reserve growth in the United Kingdom. This was confirmed by a latter more detailed study called Characteristics of North Sea Reserve Appreciation from 2002. Both studies looked at reserve growth since first production started. The author of the second study (Watkins) concluded that:

> "The size distribution of recoverable oil reserves for oil fields in the North Sea basin has much in common with that elsewhere. It is heavily skewed, with a predominance of smaller fields. The hypothesis of lognormality would not be rejected. The average field size in the UK is less than half that for Norway. In both sectors, a minority of fields account for the majority of aggregate reserves. Reserve appreciation between production start-up and the last observation year (usually 1996) for the average field in the UK was about 20%. For Norway it was close to 50%, over an average production period much the same as for the UK. This difference is marked. And given their larger average size, average appreciation of Norwegian fields approached five times that in the UK."(Watkins, 2002)

The author then goes on looking at the causes of reserve growth in the UK and Norwegian part of the North sea:

> "More light on the contrast between appreciation of Norwegian and UK fields is shed by attempting to break down estimates of recoverable reserves into the two components of oil-in-place and the recoery factor, the proportion of oil-in-place expected to be recovered before shut-down. About 75% of appreciation recorded by Norwegian fields was accounted for by increases in the recovery factor, a factor averaging some to 32% at start-up, 42% in the last observation year, a 10 percentage point increase. The rest represented appreciation of oil-in-place of some 13%, on average. The UK experience was quite different. For the field sample used, the great majority of the (lower) appreciation was accounted for by increases of oil in place of 11%; the increase in the recovery factor was some three percentage points between start-up and its value in the last observation year of 47%. However, these UK results are based on information from only about one third of the 96 fields, Norway's on 29 out of 30. The UK oil-in-place

> analysis, then, must be regarded cautiously. Moreover, comparisons between the two countries may be bedevilled by differences in reserve reporting standards." (Watkins,2002)

> "Apart from inherent variations in the physical nature of the fields, much of the difference in reserve appreciation characteristics between the two sectors has to do with the higher average recovery factors at production start-up in the UK. UK field development relied on early inception of ER [Enhanced Recovery] schemes to a greater extent than seems to have occured in Norway. Indeed, by 1996 average recovery factors in Norway still had not caught up with those in the UK."(Watkins,2002)

The first thing that we can conclude from Watkins findings is that reserve growth does occur in the North Sea. The figures he quotes, 20% for the UK and 50% for Norway have been confirmed by Francis Harper, a geologist from BP:

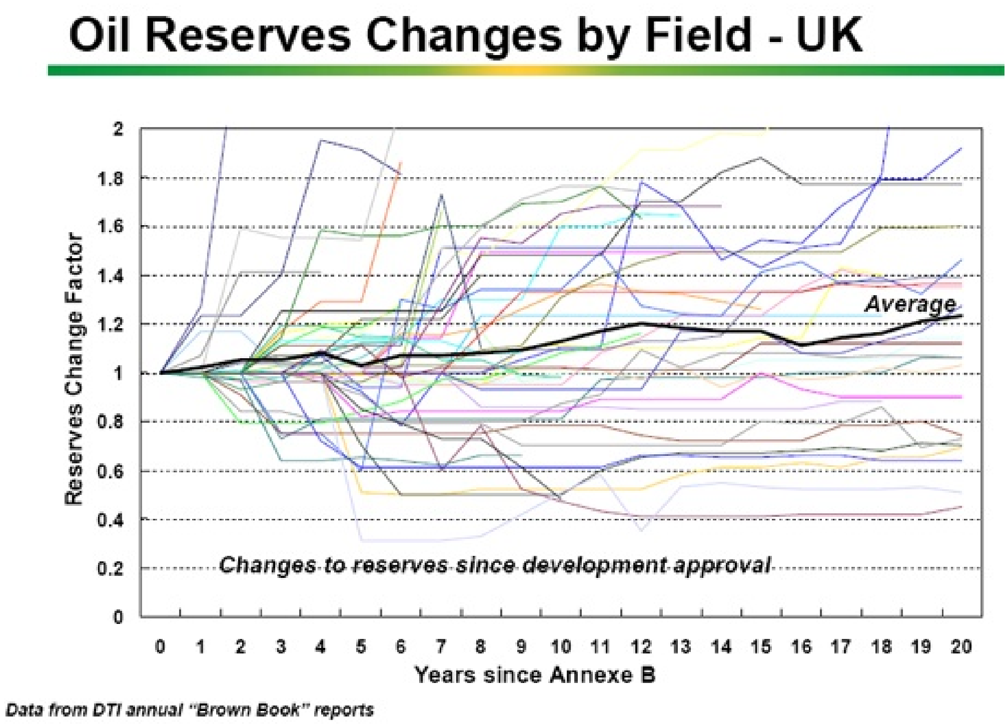

Chart 10 - Source: Francis Harper, BP

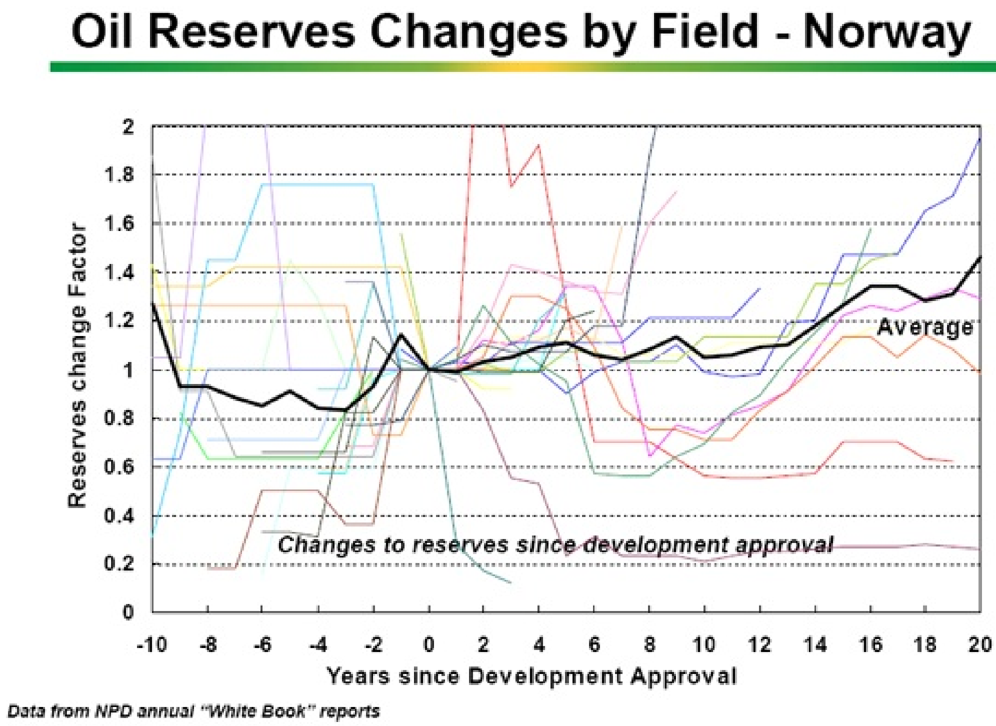

Chart 11 - Source: Francis Harper, BP

Most of the reserve growth in the United Kingdom can be explained by an underestimate of the Oil Initially In Place. The reserve estimate has been quite accurate over time. For Norway it appears that an underestimate of the recoverable reserves is the right explanation. The conclusion that an influence of technological advancement is the main cause of the increase in the recovery factor for Norway cannot be made from such aggregate figures.

Nonetheless the IEA still uses the North Sea to propagate this view of technological advancement. After showing a chart on the increase in recovery rates in the Norwegian part of the North Sea, the IEA concludes in their resource to reserves report (2006) that "conservative recovery rate increases [from enhanced oil recovery] of 5% of oil in place adds at least 300 billion barrels to the USGS figures.". Again, just like in the U.S. the only way to get a reasonable estimate of the influence of technological advancement over time on North Sea oil reserves is to look at individual cases of fields because the available aggregate data is too imprecise. Jean Laherrère already did a comprehensive field by field study of North Sea oil fields back in 2004. A few examples of his work are shown below:

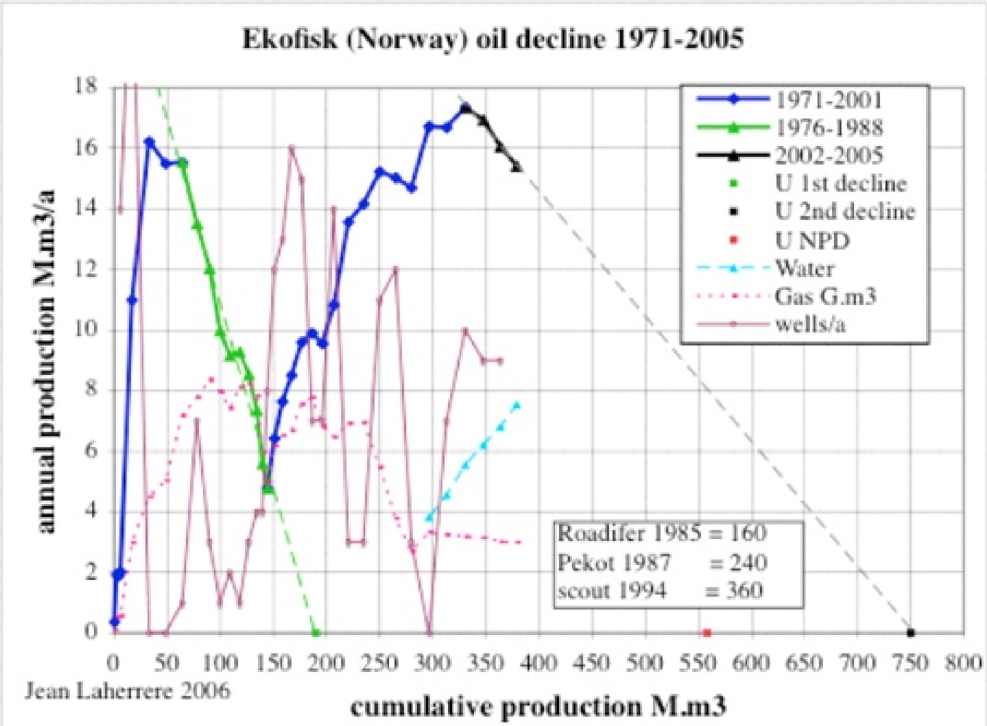

Chart 12 - Source: Jean Laherrère

Ekofisk oil field was discovered in 1969 in the Norwegian part of the North Sea with an API of 37.5. Initial production patterns led to far too low estimates for ultimate oil recovery. In the 80's however production started to increase again because the reservoir collapsed when pressure decreased, causing a subsidence of 7 meters. Soon after the collapse many wells for water injection were drilled leading to a large production jump in 1988. The collapse was caused because the reservoir comprises of a special chalk. In 2002 production started to decline again, no changes due to technological advancement have been apparent so far.

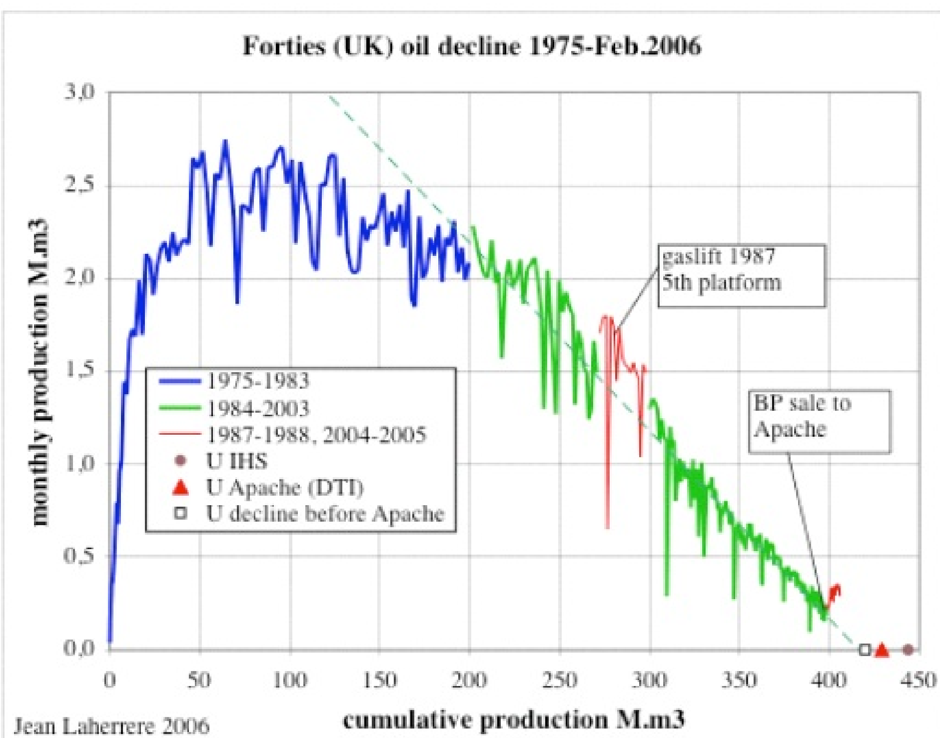

Chart 13 - Source: Jean Laherrère

Forties is an oil field in the UK part of the North Sea discovered in 1970 with an API between 43 and 45 degrees. Production followed a normal pattern in the field, showing no increase in reserves over time. A gaslift platform was introduced in 1986, which slightly increased production for a few years until it dropped again to the old production level.

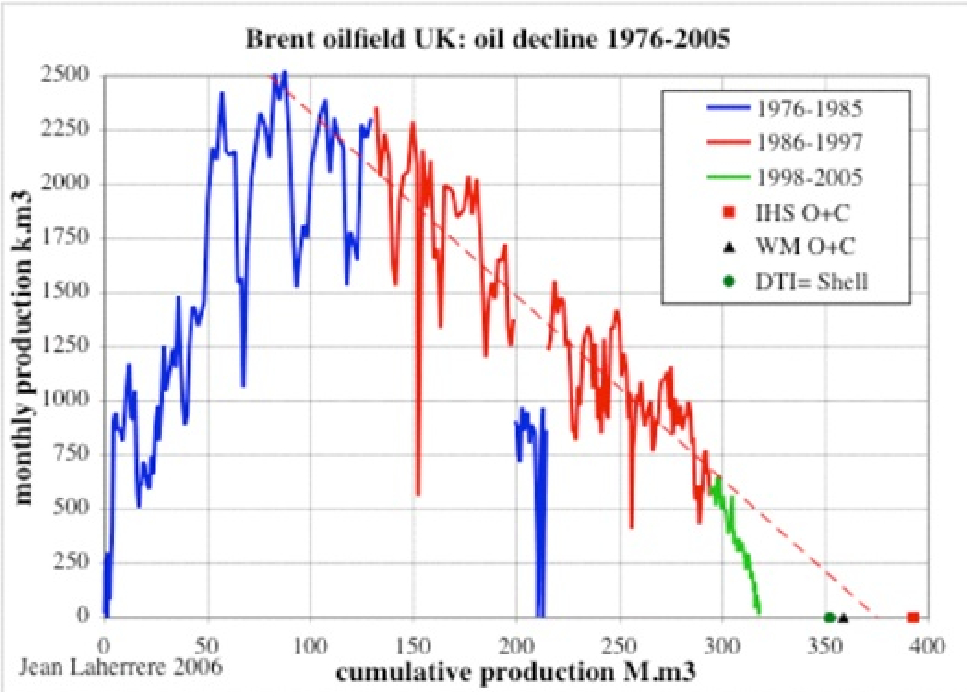

Chart 14 - Source: Jean Laherrère

Brent oil field in the UK part of the North Sea was discovered in 1970 with an API of 38 degrees. Production followed a normal pattern until 1988. Due to the Piper Alpha Platform fire production was disturbed between 1989 and 1991. Afterwards, oil production quickly returned to normal leves and continued towards the expected oil recovery path. At the end of the fields life, however, oil production collapsed, leading to a lower then expected ultimate recovery. Reserves did not grow but declined in Brent oil field.

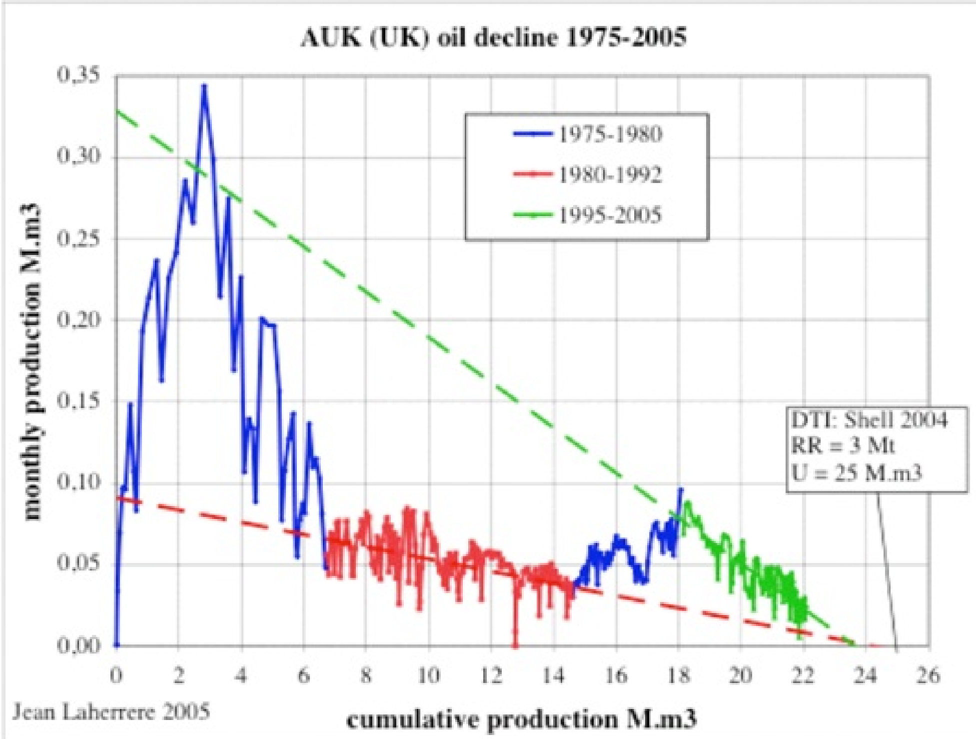

Chart 15 - Source: Jean Laherrère

Auk is an oil field in the UK part of the North Sea which was discovered in 1971. Production followed a normal pattern of peak and slow decline until the introduction of Horizontal wells in 1993 (start of second blue part of the graph). Production increased until 1995, after which a sharp decline set in. The implementation of horizontal and multilateral drilling did not change the ultimate recovery of the field. Schneider in AAPG memoir 74 from the year 2000 mentioned that the recovery factor of the field would increased from 17% to 30% from the start-up to the end of the fields life:

> "The estimated ultimate recovery in 1988 was 93 million barrels or about 13 million barrels remaining (Trewin and Bramwell 1991). The estimated ultimate recovery in 1998 is about 180 million barrels or about twice the 1988 estimate. A major share of the reserve additions at Auk is from a large field extension (Auk North) found previously by seismic, but considered uneconomic for many years. Previous work by Shell/Esso showed Auk North production was not feasible to develop from a satellite platform or from extended reach wells from existing Auk platforms. Improvement in economics that make Auk North development now possible for Shell/Esso comes from the use of multilateral wells from existing Auk development wells and the use of electric submersible pumps deployed and retrieved on coil tubing without the need of a semi-submersible rig." (Schneider, 2000)

The expected extension (AUK noth) has, however, not come on-stream yet. The claimed incerase in the recovery factor is not visible in the graph.

While it is apparant that reserve growth is a large factor in the North Sea, it is not so clear to what cause. In the UK it appears that it was mainly due to an underestimates of Oil Initially In Place, in Norway mainly due to underestimates of ultimately recoverable reserves. Technology does not appear to have a large impact, but this could be the wrong conclusion. More study on the North Sea would be necessary to determine what the exact cause of reserve growth is.

Summarizing and Concluding remarks

1) Reserve growth occurs in all the three examined regions, Russia, the United States and the North Sea.

2) The huge increase in reserves due to reserve growth in the United States, which sets the US apart from other countries, can be explained because of the unique practice of reporting proven reserves only. This makes extrapolation of the amount of reserve growth in the United States not applicable towards countries that do report in a different manner, which are most other countries in the world. It is impossible to tell from aggregate figures what the influence is of technological advancement on reserve growth. Separate case studies show that in uconventional heavy oil fields, technological advancement plays a main role in reserve growth. In conventional fields no clear role of technological advancement is visible.

3) In Russia most reserve growth in the Siberian basin occurs in the initial phase after discovery/production in oil fields. No reserve growth occurs in later stages of lives of oil fields that have been studied. Reserve growth in Russia appears to be mainly due to initial underestimates of the oil fields potential, not to technological advancement.

4) In the North Sea reserve growth mainly occured to underestimating the Oil Initially in Place in the United Kingdom, while in Norway it was mainly due to changes in the reserves either by underestimates of reserves and/or by technological advancement. Far less reserve growth occured in the UK then in Norway. In the reserve reporting in the UK, enhanced oil recovery was already being taken into account, while in Norway this was not the case. This could explain the difference between Norway and the UK, with respect to the high increase in the recovery factor in Norway and the lower increase in the UK. However, is the difference due to the EOR techniques, or simply due to underestimating the recoverable reserves because of other reasons? And more importantly, can these effects be extrapolated to the future? If the increase in the recovery factor is caused by EOR techniques, this would probably be the case. Single oil field cases do not show an increase in reserves in later stages of fields lives due to the application of enhanced oil recovery techniques.

5)While technology seems to play a part, reserve growth appears to be mainly a function of reserve accounting. Due to more accurate reporting, reserves grow over time. Technological advancement could very well play a role in reserve growth of conventional reservoirs, but this cannot be concluded from the data available in the studies above. This makes claims that reserve growth will occur in the future as it did in the past unreliable.