The Oil Drum
DISCUSSIONS ABOUT ENERGY AND OUR FUTURE

Khurais Me A River

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Khurais. It is the best of fields. It is the worst of fields. It is another chip off the old block, destined to prolong Saudi Arabia's dominance as an oil producer. It is a chink in the armor of the Saudi Oil Miracle, a symbol of a lesser future. Do tell, which is it? Amidst a lot of speculation, there are a few knowns. The Khurais Megaproject is the largest integrated development project in Saudi Aramco history. Slated for completion at the end of 2009, it includes the expansion of oil production in the Khurais, Abu Jifan, and Mazalij fields. These fields lie approximately midway between Riyadh and the Ghawar oil field, and sea water for injection will be piped in from the Arabian Gulf near Dharahan. The completed project is stated to have a capacity of 1.2 million barrels of oil per day. This article will present an early look at the Khurais development using satellite images and a review the scant data available for Khurais in an attempt to assess its prospects in light of much skepticism.

This article is another in a series on the oil fields of Saudi Arabia studied using Google Earth. For an introduction to this topic, see the first few articles at Satellite o'er the Desert.
For a previous Oil Drum post on Khurais, see this entry by Heading Out: From the old to the newer, or a thought for Khurais and its companions.

Great Expectations

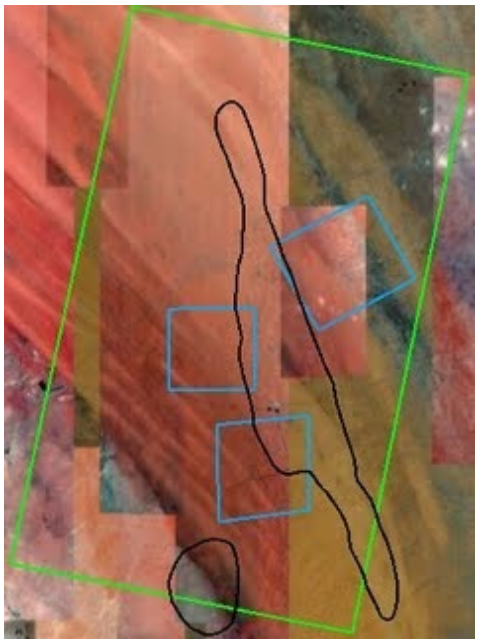
In "Twilight in the Desert", Matt Simmons questioned whether Khurais could possibly produce that much oil given its spotty prior production record. In contrast, Saudi Aramco lauds Khurais as "the fourth largest oil field in the world" in its Saudi Aramco 2006 Annual Review. Which of these views of Khurais' potential is correct? In contrast to the situation for Ghawar, there is only a limited amount of public data available for Khurais upon which to base an external opinion. Simmons' assessment was based on two Society of Petroleum Engineers (SPE) papers. The first of these, *A Production and Operation Review of the Khurais Gas Lift Project* (SPE 11447) by Chornoboy and Englehart, addresses efforts in the early 1980s to increase production. The second, a 2002 paper by Al-Afaleg et. al. entitled *Successful Integration of Sparsely Distributed Core and Welltest Derived Permeability Data in a Viable Model of a Giant Carbonate Reservoir* (SPE 77743-MS), describes an attempt to model previous and potential future production for Khurais using data from well logs and core measurements. For those of us playing along at home, the latter provides some information on the production history and field geology as well as well maps which facilitate a satellite-based investigation of the development status as of December 2007.

Satellite Imagery for Khurais Fields

Shown at right is the geographic setting for the three fields which comprise the Khurais project. The boundary for the Khurais field, corresponding to the oil/water contact, was obtained from well layouts in SPE 77743. The boundaries for the other fields are not explicitely defined in that paper, but there is enough supporting data to enable good approximations.

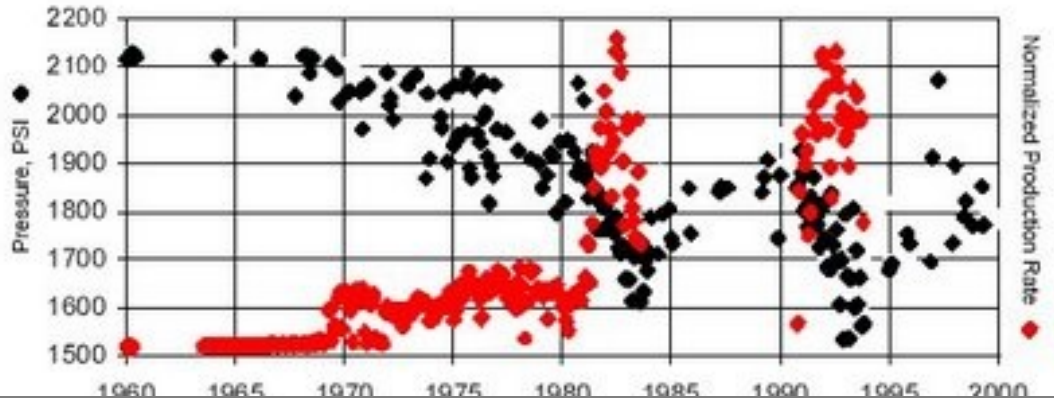
A fourth field often included as one of the satellites of the Khurais complex, Qirdi, has apparently become the southern tip of Khurais. The total area for the three fields is approximately 1600 sq. km (620 sq. miles), with the Khurais field accounting for 2/3 of the total; this is an area nearly equal to that of the Uthmaniyah section of the Ghawar field.

Google Earth currently (2/2008) displays high resolution DigitalGlobe imagery for the northern half of the Khurais field and nearly all of Abu Jifan dating to mid June 2006. There are also DigitalGlobe preview images of the same vintage images covering the remaining areas. DG previews dating to September 2007 also cover small sections of Khurais, as indicated with blue outlines in figure at right. Finally, two Spot5 preview images provide a blurry but nonetheless informative picture from the end of 2007 in the region of Khurais within the green outline.



Khurais Production History

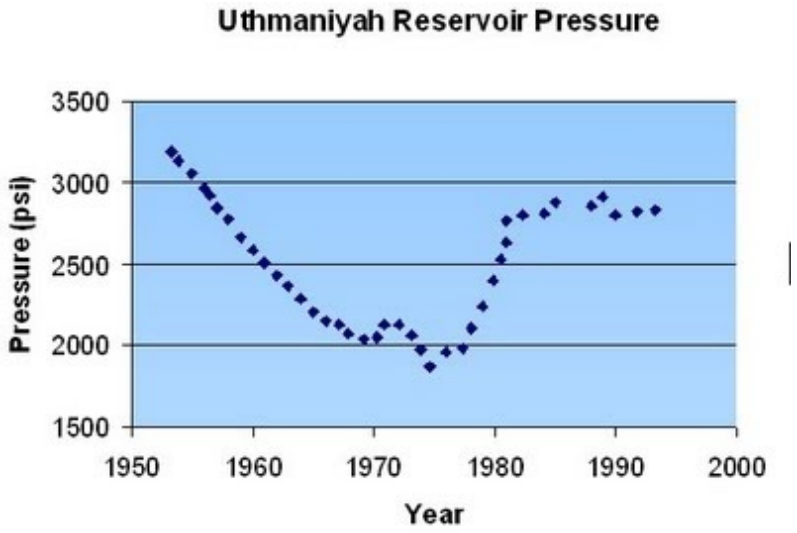
Why hasn't Khurais been more fully developed? Khurais was discovered in 1957, but oil was not produced to any large extent until the 1970s. Shown below is a composite of oil production and Arab-D reservoir pressure based on data from SPE 77743. Production was via primary depletion. The production increase resulting from the 1980s Gas Lift Project described in SPE 11447 is apparent, as is a later production spurt in the 1990s. The steady drop in reservoir pressure as the oil is extracted is indicative of insufficient support from the aquifer.



Khurais production (red) and Arab-D reservoir pressure (black) 1960-2000

The production values are normalized, but Simmons gives a value for overall field production as 68,000 barrels per day in 1980 and reaching a maximum of 144,000 bpd in 1981 (although the above figure suggests a year or more later). The number of flowing wells in the 1970s is unknown, but at least 50 wells (some of which were new) were contributing to the rate in the early 1980s. A total of 50 wells would yield a flow of somewhat less than 3000 bpd from each.

The pressure behavior obviously does not portend well for long-term production, but it must be remembered that the field was being produced under primary depletion. For example, compare this with the pressure drop observed in the Uthmaniyah area of Ghawar prior to the onset of water injection:



Arab-D reservoir pressure in Uthmaniyah. Data from Benkendorfer et. al., "Integrated Reservoir Modelling of a Major Arabian Carbonate Reservoir" (SPE 29869)

Water injection in Uthmaniyah first began along the flanks in 1966 with gravity assist and then with a pressurized system in 1973. According to one estimate, pre-injection oil production was likely under 400,000 bpd--but still perhaps 5-10 times higher than that from Khurais. Differences in the quality of the reservoir might be the primary cause of this. However, it may also be important that the initial static pressure in Khurais is quite a bit lower than that for the Ghawar fields such that the primary drive mechanism is solution gas rather than aquifer. In any case, it is somewhat misleading to compare oil production from Ghawar under water injection with Khurais under its own steam.

What of the boost in production in the 1980s? This effort to increase production was misread by Simmons as "gas injection", a technique used in 'Ain Dar and Abqaiq in earlier years to maintain reservoir pressure. What was actually employed in Khurais was "gas lift". The distinction between these two is given by Schlumberger as:

> gas injection:
>
> - *A reservoir maintenance or secondary recovery method that uses injected gas to supplement the pressure in an oil reservoir or field. In most cases, a field will incorporate a planned distribution of gas-injection wells to maintain reservoir pressure and effect an efficient*

sweep of recoverable liquids.

gas lift:

- *An artificial-lift method in which gas is injected into the production tubing to reduce the hydrostatic pressure of the fluid column. The resulting reduction in bottomhole pressure allows the reservoir liquids to enter the wellbore at a higher flow rate. The injection gas is typically conveyed down the tubing-casing annulus and enters the production train through a series of gas-lift valves. The gas-lift valve position, operating pressures and gas injection rate are determined by specific well conditions.*

SPE 11447 does report problems in some of the 50 wells (in Khurais) where gas lift was employed, but gives an overall positive assessment of the effort. Since it was written while production was ongoing, any reason for stopping production (beyond the decline in the price of oil) is not clear from the paper. Curiously, the Gas Lift project is not mentioned at all in the latter 2002 paper (SPE 77743), even though this would seem to have been critical in accurately modeling oil production during the 1980s and 1990s.

2001 Well Survey (SPE 77743)

By 2001, there were 131 wells placed in the Khurais complex, with 80 of those located in the Khurais field itself. Saudi Aramco initiated a study to determine the best strategy for a full development of the complex. Well logs and measurements on well core plugs were used to determine reservoir stratigraphy, porosity, and permeability. These data were then used to construct a 3D model of the oil-bearing zones. Shown at right are the 2001 wells identified using Google Earth. Superimposed on the image are contours indicating the top of the Arab-D reservoir, the major oil-bearing structure in Khurais. This formation is an asymmetric anticline with dips averaging 2 degrees and 8.7 degrees on the eastern and western flanks respectively. (Click image for a larger version).

Where the Oil Is

Khurais has three oil-bearing reservoirs: the Arab-D and Hanifa (both API 33 degrees), and Fadhili (API 36 degrees). Most of the wells have been drilled into the Arab-D, with an unknown number into the Hanifa. At least 7 wells have been cored in the Fadhili reservoir, but it has not been produced. SPE 77743 presents a stratigraphic column for the Arab-D reservoir. Unfortunately, absolute thickness of the Arab-D is not revealed. However, this reference:

Anthony E . Adams and Mohamed S . Al-Zahrani, PALAEOBERESELLIDS (DASYCLADACEANS) FROM THE UPPER JURASSIC ARAB-D RESERVOIR, SAUDI ARABIA, PALAEONTOLOGY, VOLUME 43 (2000)

describes a well in south Khurais with an Arab-D layer of 65 meters (213 feet) thick lying at a depth span of 1647-1712 meters (5400'-5617'). Even less has been revealed about the thickness or areal extent of the Hanifa (or Fadhili) reservoirs, although the thickness of the Hanifa in

Abqaiq is about 100 m (300 feet) with an areal extent equal to 14% of that for the Arab-D (JoulesBurn, blog post in preparation).

Arab-D Porosity

The stratigraphic column in SPE 77743 includes porosity log measurements. In contrast to Ghawar, where the Arab-D zone 2 has the highest quality, the sweet spot in Khurais is zone 1 (the upper 40%). Zone 2 occupies the middle 20% of the Arab-D, with somewhat lower porosities. The remaining 40% is zone 3, with still lower porosity. The authors excised the scale information, but if one assumes the major divisions correspond to 10% intervals, I have estimated average porosities of 24%, 12%, and 5% for the three zones. Irrespective of the absolute porosity values, this implies that 2/3 of the oil in the Khurais Arab-D lies in zone 1. Below the oil-bearing layers lies 300 feet of the impervious Jubailah formation followed by the Hanifa reservoir. As is the case in Abqaiq, there are fractures through the Jubailah which provide pressure continuity between the Arab-D and Hanifa reservoirs with all sorts of unfortunate consequences.

Permeability

As per SPE 77743, permeability of the Arab-D reservoir in Khurais was measured both from core samples (small scale permeability) and from well tests (large scale). Core permeabilities, presented in cumulative probability distributions, range from a median value of 100 mD in the north to about 5 mD in the south with little variance east to west. However, the effective permeabilities measured in the wells is often much higher (over 10x), particularly along the crest of the anticline, due to fracturing. It was because of this high permeability that proportionally more wells were drilled into the crest. Upon water flood, the risk will be that wells drilled near these fractures could water out early. It is perhaps for this reason that a 3D seismic study was conducted over Khurais and Abu Jifan from 2004-2006 in order to dilineate the fractures.

How Best to Get the Oil Out?

The Khurais oil field seems to have many of the challenges encountered previously by Saudi Aramco before in other fields. Haradh III is one model for how Khurais might be developed, given the lesser quality of the rock relative to the rest of Ghawar as well as the problems with fractures. The challenge of exploiting two reservoirs (Arab-D and Hanifa) has been confronted in Abqaiq, although not (as of yet) successfully. How will this field be developed?

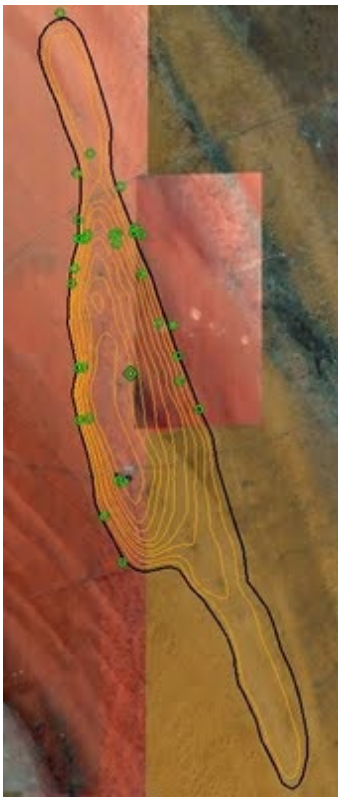
A June 2006 announcement by Abd Allah S. Al-Saif, Aramco senior vice-president exploration and producing, revealed the following:

> *...the Khurais development plans include drilling 310 horizontal wells and installing facilities for injecting 2 million b/ d of seawater. Included in the 310 wells are 125 water injection wells and 17 observation wells. Al-Saif said the producing wells will have single 1-2-km long laterals and be instrumented with modern real-time, intelligent, downhole completions with "smart" electric submersible pumps. The injection wells will have 1.5-km long laterals, he said.*

One surprise is the use of relatively short single-lateral horizontal wells, and another is the use of electric pumps. In contrast, the two most recently (or nearly) completed megaprojects, the Haradh III increment and the Khursaniyah (AFK) expansion, both utilized multi-lateral

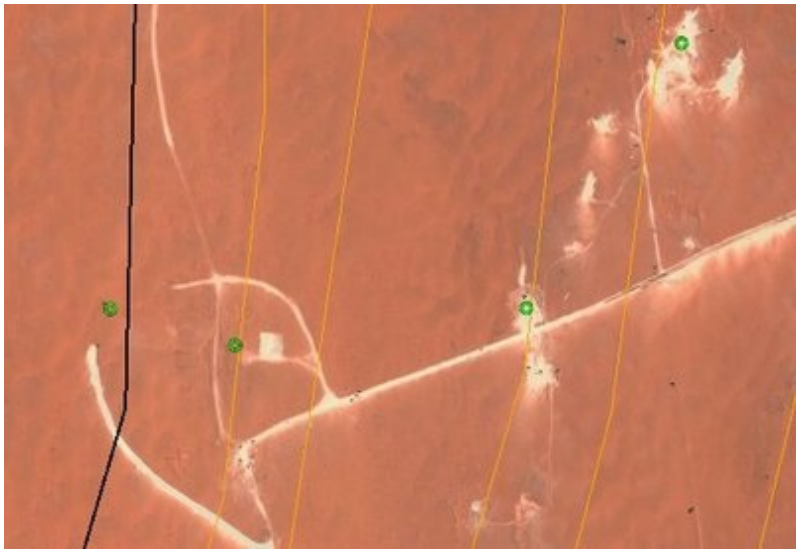
maximum reservoir contact (MRC) wells for producers. Achieving 1.2 million barrels per day from 168 producers requires an average well productivity of 7142 bpd. By comparison, the single-lateral horizontals in the Haradh II increment reportedly only provide about 3000 bpd of production. Will these be sufficient? Time and future satellite imagery will tell.

Quick, Let's Get Started!



Saudi Aramco met with contractors in March 2006, and in early June announced that Halliburton had been awarded a 3-year contract to drill the wells. Based on satellite images taken less than 2 weeks later, the awardee wasted little time getting things going. Shown at right is the Khurais field with new well development sites indicated by the green placemarks. One drilling rig is also being readied (green diamond in the center of the field). Most of the initial drilling sites are for injectors including a pair on the western flank shown in the closeup below.

Most of the sites are still being prepared, and many earth-moving vehicles are visible as seen below for a group of sites near the northern "bottleneck".

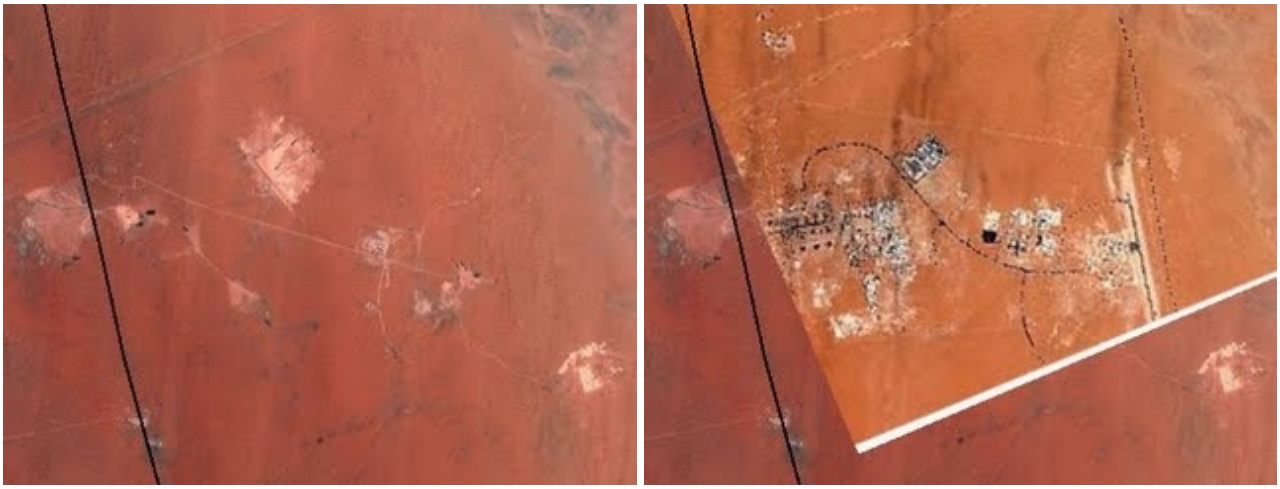


Such a rapid deployment of equipment does not seem possible, even with Halliburton now calling the U.A.E. home. Either they knew well in advance of the contract announcement, or perhaps Saudi Aramco initiated the drilling themselves. It is also noteworthy that this development is occuring nearly simultaneously with the extensive drilling of new wells in Ghawar. Outside the

field, the graded areas directly to the east are the likely sites for additional infrastructure being constructed including gas and water facilities. Foster Wheeler was awarded a contract a year prior which included a central processing facility.

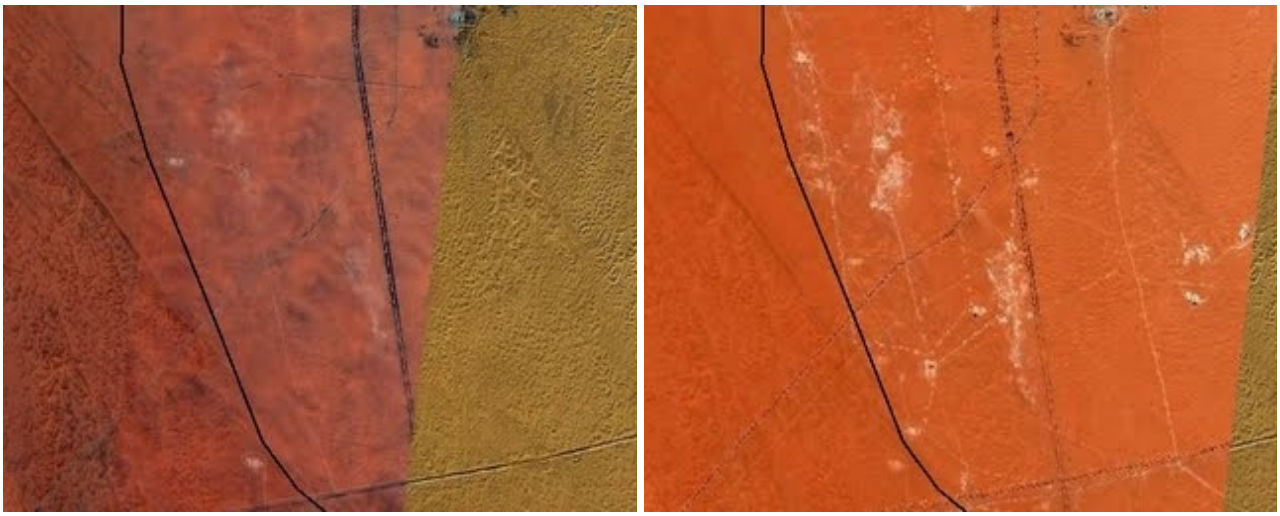
September, 2007

Moving ahead about about 15 months, an updated picture is obtained using low-resolution preview DigitalGlobe images as overlays. There as been considerable progress on the central processing facilities and seemingly the construction of an airstrip.



Central Processing facilities east of Khurais in June 2006 (left) and September 2007

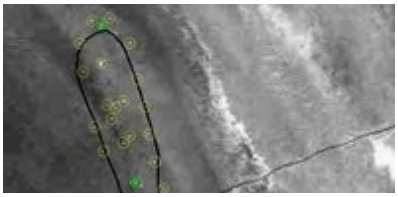
Similarly, a region to the southwest also shows a number of new well locations.



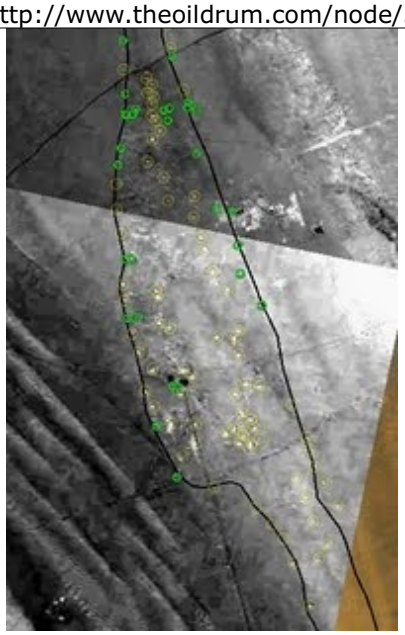
Well development in SW Khurais in June 2006 (left) and September 2007

December 2007

As noted earlier, there are two December, 2007 images from the Spot5 instrument which cover nearly all of Khurais. These images are monochrome, and the preview images for these have even less resolution than the DigitalGlobe previews. However, the fresh sites are remarkably distinct even at this resolution as shown at right.



The sites visible in 2006 are indicated with green placemarks, and faint yellow circles indicate additional identified sites for the end of 2007 (Again, click image for larger version).



The development plan at this point appears to include injectors spaced 1.5 to 3 km apart with producers located 4 km updip. In addition, there are several clusters of producers where the well spacing is also about 1.5 km, including a large cluster in the south central part of the field. I have tentatively identified about 60 additional sites which, when added to those found in 2006 (about 20), gives perhaps a third to a half of the number allotted for the Khurais field portion of the project. Of course, given the, given the quality of the 2007 images used, the uncertainty is large.

Comparison with Haradh III

Although the Khurais project was planned with single instead of multiple laterals, it is still interesting to compare this picture with the layout for the Haradh III increment. In a previous article, the Haradh III well layout was aligned with the satellite imagery, as show at right. The spacing of injectors around the periphery and distance from the injection line to the producers is similar to that observed for Khurais.

Khurais Development vs. Other Drilling

It is clear that development of Khurais has ramped up considerably in 2007 relative to 2006. Of interest is the magnitude of this effort relative to maintaining production from existing fields. Saudi Aramco seemed to provide an answer to this question as reported by *Oil Daily Reports*:

> In December 2006, Saudi Aramco announced its 2007 exploration and drilling budget of almost $4 billion - nearly double the draft budget and full quarter of Aramco's 2007 capital budget.
>
> ...Aramco plans to drill 427 onshore and offshore crude oil development wells in 2007. Approximately 134 wells will be in or near Ghawar, while 85 will be drilled in Khurais, and some 50 drilled in Khursaniya.

This continued drilling of Ghawar in 2007 is comparable to what I found for 2006. If what the satellite imagery above shows is only reflective of 85 wells (plus a few in 2006), 2008 should be a busy year in Khurais.

Abu Jifan and Mazalij

I haven't presented any imagery from these fields, and there has definitely been activity there in

the last couple of years. However, the lack of high resolution imagery for Mazalij prevents any clear before and after comparisons, and the (real or apparent) colorations in the imagery for Abu Jifan makes me a little queazy. For example, look at the image below, found on the east side of the field. I can't identify this as anything related to oil production, but there is a similar site not too far away. It looks rather like it's located in Mordor. If you look closely, you can possibly spot orcs and maybe smell the sulfur.

Unknown development in the Abu Jifan oil field (view in Google Maps)

Conclusion: the Good, the Bad, and the Unknown

An early glimpse of the Khurais development has been afforded by satellite imagery using Google Earth. A review of two SPE papers on Khurais suggests more favorable prospects for Khurais reaching its stated production targets than often assumed, although whether this can be done with the planned number of wells remains to be seen (hopefully by satellite). The good: a large field with good porosity in the upper part of the Arab-D reservoir, mixed permeability (at least not overly tight like Shaybah), and light grade crude. The bad: fractures at the crest (the double-edged sword of higher early production but with earlier water encroachment). The unknown: less effective waterflood (as suggested by the need for electric pumps), whither simultaneous (but likely problematic) production from the Hanifa reservoir. One other unknown is whether the fields, once "commissioning activities have been completed"*, will run at "capacity". </sarcasm>

**see the Khursaniyah project delay*