Peak Phosphorus

Posted by Prof. Goose on August 17, 2007 - 10:00am
Topic: Alternative energy
Tags: agriculture, depletion, hubbert linearization, original, phosphorus, recycling
[list all tags]

This is a guest post by Patrick Déry and Bart Anderson. Patrick Déry is a physicist, energy, agriculture and environment analyst and consultant in Quebec, Canada. Bart Anderson is a former reporter, teacher and technical writer; he currently is co-editor of Energy Bulletin.

Peak oil has made us aware that many of the resources on which civilization depends are limited.

M. King Hubbert, a geophysicist for Shell Oil, found that oil production over time followed a curve that was roughly bell-shaped. He correctly predicted that oil production in the lower 48 states would peak in 1970. Other analysts following Hubbert's methods are predicting a peak in oil production early this century.

The depletion analysis pioneered by Hubbert can be applied to other non-renewable resources. Analysts have looked at peak production for resouces such as natural gas, coal and uranium.

In this paper, Patrick Déry applies Hubbert's methods to a very special non-renewable resource - **phosphorus** - a nutrient essential for agriculture.

In the literature, estimates before we "run out" of phosphorus range from 50 to 130 years. This date is conveniently far enough in the future so that immediate action does not seem necessary. However, as we know from peak oil analysis, *trouble begins not when we "run out" of a resource, but when production peaks*. From that point onward, the resource becomes more difficult to extract and more expensive.

Physicist Déry applied the technique of Hubbert Linearization to data available from the United States Geological Survey (USGS)[1] to phosphorus production in the following:

- The small Pacific island nation of Nauru, a former phosphate exporter.
- The United States, a major phosphate producer.
- The world.

He tested Hubbert Linearization first on data from Nauru to see whether he could have predicted the year of its peak phosphate production in 1973. Satisfied with the results, he applied the method to United States and the world. He estimates that U.S. peak phosphorus occurred in 1988 and for the world in 1989.

Phosphorus - its role and nature

Phosphorus (chemical symbol P) is an element necessary for life. Because phosphorus is highly reactive, it does not naturally occur as a free element, but is instead bound up in phosphates. Phosphates typically occur in inorganic rocks.

As farmers and gardeners know, phosphorus is one of the three major nutrients required for plant growth: nitrogen (N), phosphorus (P) and potassium (K). Fertilizers are labelled for the amount of N-P-K they contain (for example 10-10-10).

Most phosphorus is obtained from mining phosphate rock. Crude phosphate is now used in organic farming, whereas chemically treated forms such as superphosphate, triple superphosphate, or ammonium phosphates are used in non-organic farming.

Philip H. Abelson writes in *Science*:

> The current major use of phosphate is in fertilizers. Growing crops remove it and other nutrients from the soil... Most of the world's farms do not have or do not receive adequate amounts of phosphate. Feeding the world's increasing population will accelerate the rate of depletion of phosphate reserves.

and

> ...resources are limited, and phosphate is being dissipated. Future generations ultimately will face problems in obtaining enough to exist.

It is sobering to note that phosphorus is often a limiting nutrient in natural ecosystems. That is, the supply of available phosphorus limits the size of the population possible in those ecosystems.

More information:

- Understanding Phosphorus and its Use in Agriculture from the European Fertilizer Manufacturers Association.
- Phosphate Primer by Florida Institute of Phosphate Research.

Prospect of a Phosphorus Peak

In his frightening book *Eating Fossil Fuels* [3], Dale Allen Pfeiffer shows that conventional agriculture is as oil-addicted as the rest of society. A decline in oil production raises questions about how we will feed ourselves.

In the same way, agriculture is addicted to mined phosphates and would be threatened by a peak in phosphate production. As the U.S. Geological Survey (USGS) wrote in summary on phosphates (PDF):

> There are no substitutes for phosphorus in agriculture.

Fortunately, phosphorus - unlike oil - can be recycled. Responses to a phosphorus peak include re-creating a cycle of nutrients, for example, returning animal (including human) manure to cultivated soil as Asian people have done in the not-so-distant past [4].

Hubbert Linearization

Tools that have been used for analyzing peak oil can be applied to phosphate production. As we will see, phosphorus production follows a more-or-less bell-shaped (parabolic) curve, just as oil production does.

Hubbert's parabolic curve is based on a differential equation explained by Stuart Staniford:

> The idea behind the equation is that early on, the oil industry grows exponentially - the annual increase in production is proportional to the total amount of knowledge of resources, oil field equipment, and skilled personnel, all of which are proportional to the size of the industry. ...
>
> Later, however, the system begins to run into the finiteness of the resource - it gets harder and harder to get the last oil from the bottom of the depressurized fields, two miles down in the ocean, etc, etc.

To estimate future production and total production, some analysists have turned to the technique of Hubbert Linearization (H-L).

Hubbert Linearization was first developed by geologist Kenneth Deffeyes, an associate of M. King Hubbert. The technique has been discussed by analysts such as Stuart Staniford, Jeffrey J. Brown and Robert Rapier at The Oil Drum. The term Hubbert Linearization was coined by Stuart Staniford.

In Hubert Linearization, the production data from the bell-shaped Hubbert curve is plotted as a line. On the graph:

> the y-axis (vertical) is P/Q where
> P = annual production and
> Q = total production to date
>
> the x-axis (horizontal) is Q (total production to date).

By extending the line in the graph, one can estimate Ultimate Recoverable Reserves (URR) for the region (Qt).

This paper purposely minimizes the math so as to reach a wide audience; however, much more detail on H-L is available online. For example:

Hubbert Linearization (Wikipedia)
In Defense of the Hubbert Linearization Method
Another Way of Looking at CERA by Stuart Staniford
When Does Hubbert Linearization Work? by Stuart Staniford
Predicting the Past: The Hubbert Linearization by Robert Rapier (H-L skeptic)

Applying Hubbert Linearization to Phosphates

For the purposes of this paper, Déry looked at data for commercial phosphate (26-34% of P2O5). Other reserves of rock phosphate with lower concentrations of P2O5 do exist, but, just as with tar sand for oil production, they are more costly to exploit - economically, energetically and environmentally.

Using data from United States Geological Survey (rock phosphate production historical data series), Déry did a Hubbert Linearization for United States and for world rock phosphate production.

Results were stunning. The theoretical logistic curve fits almost perfectly with the real data curve. Déry found that we have already passed the phosphate peak for the United States (1988) and for the world (1989).

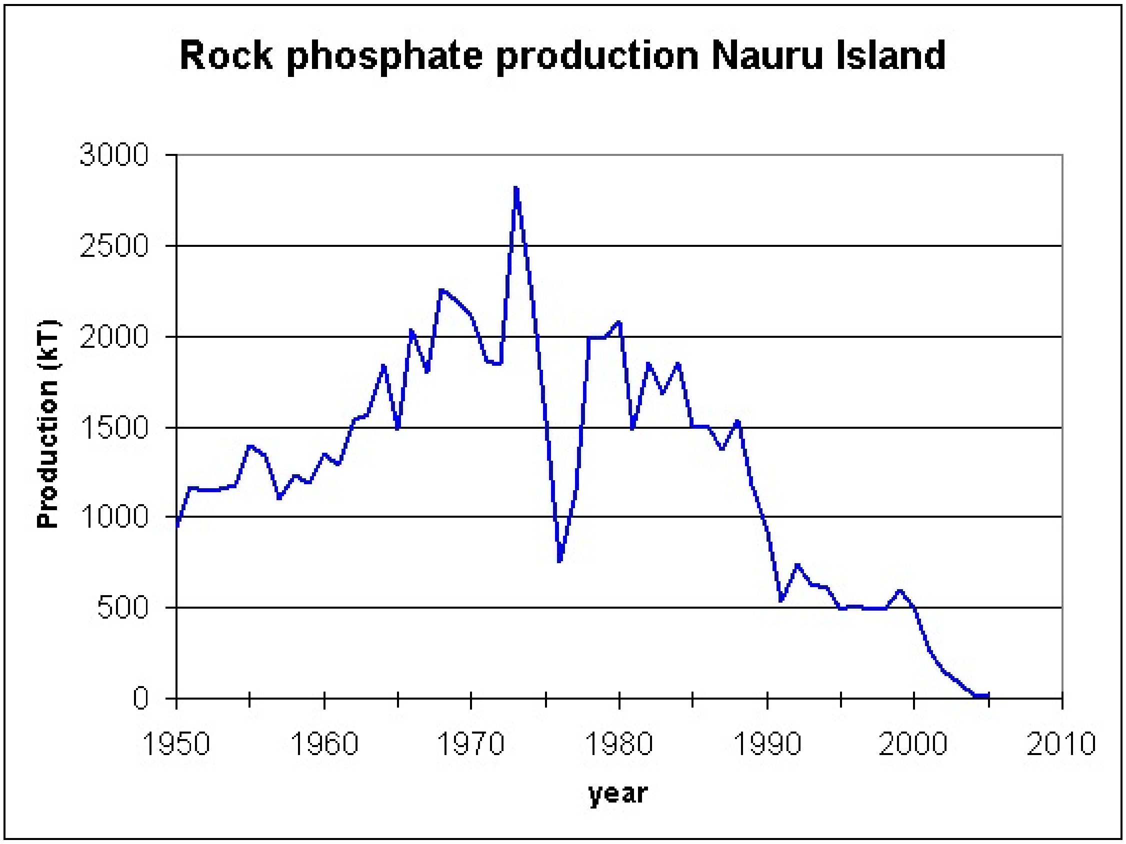
Nauru

However those results seemed too perfect, so Déry tested the method on an almost depleted region of rock phosphate production, a case similar to that of United Stated for oil. A small island in the South Pacific called Nauru appeared to be an ideal case. The Nauru Island is 21 km² with only one economic resource (besides being a fiscal paradise!): rock phosphate. This resource has been almost entirely depleted since 2005.

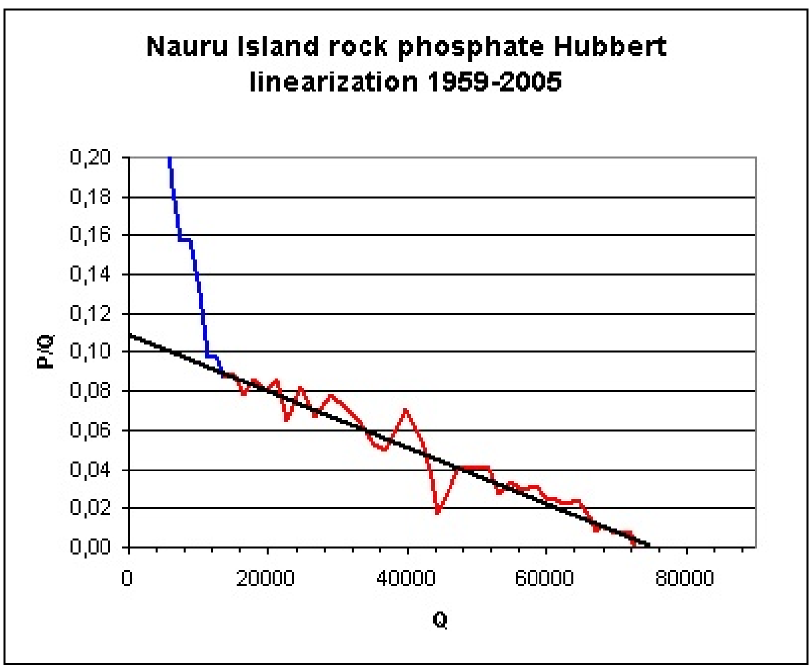
According to the CIA World Factbook:

> ...intensive phosphate mining during the past 90 years - mainly by a UK, Australia, and NZ consortium - has left the central 90% of Nauru a wasteland and threatens limited remaining land resources

Plotting the rise and fall of rock phosphate production on Nauru yields this graph:

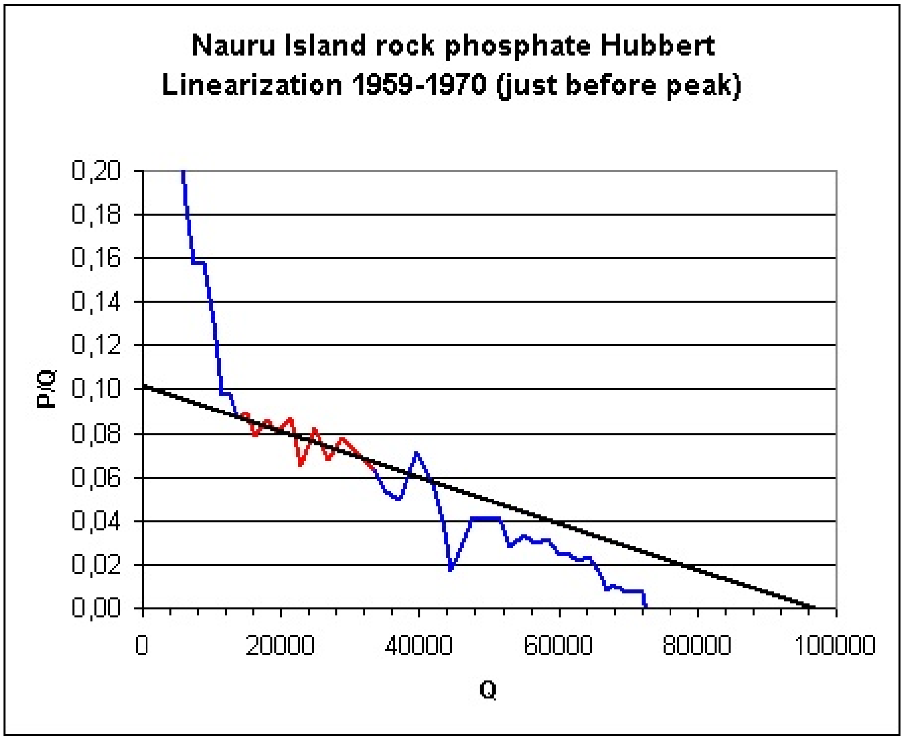


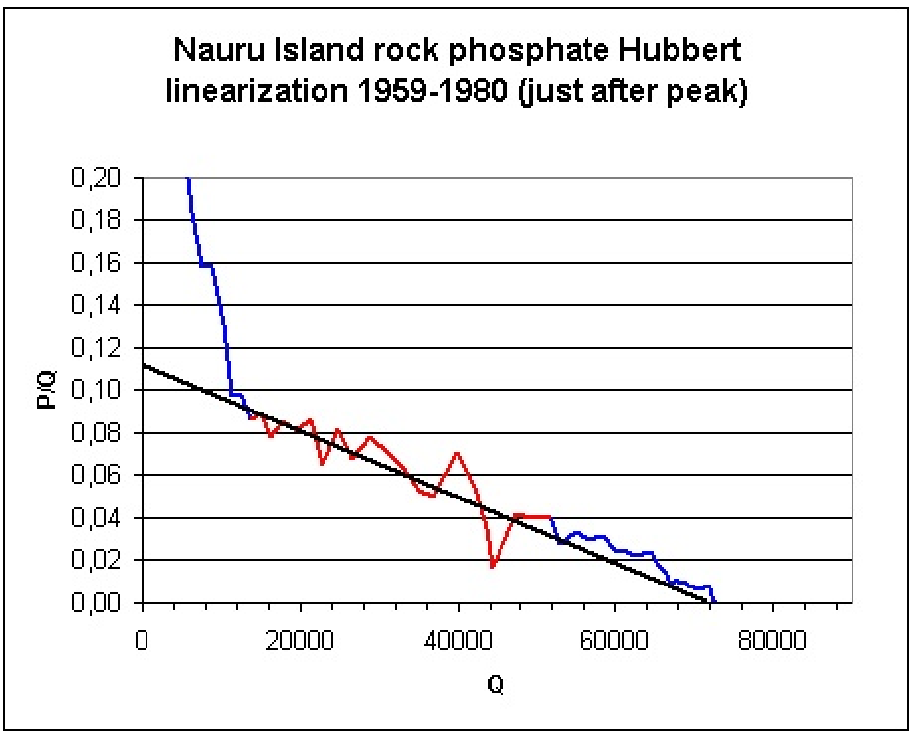
To begin with, Déry made a Hubbert Linearization with the stabilised data (linear trends since 1959) and found an Ultimate Recovery Reserves (URR) equivalent of 77 000 kT and a peak of rock phosphate production in 1973.



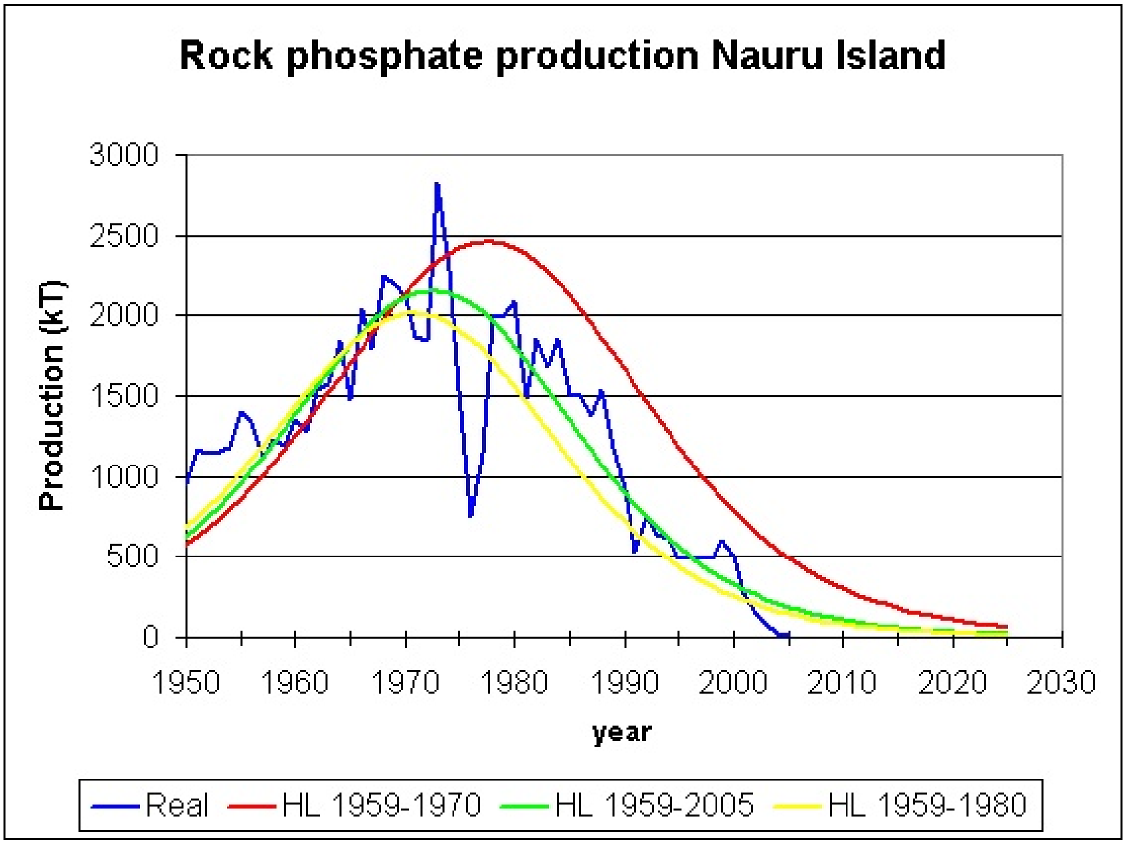
Looking at the results, he asked himself a question: would it be possible to predict the URR and the profile of future production just before the peak or just after? To get an answer, he used the data from 1959 to 1970 (just before peak) and 1959 to 1980 (just after peak). The results were :

- Just before peak : URR = 97 000 kT; peak date: 1978
- Just after the peak : URR = 72 000 kT; peak date 1971





If we calculate to obtain production curves for all these scenarios and put them on the same graph with real data, we obtain:

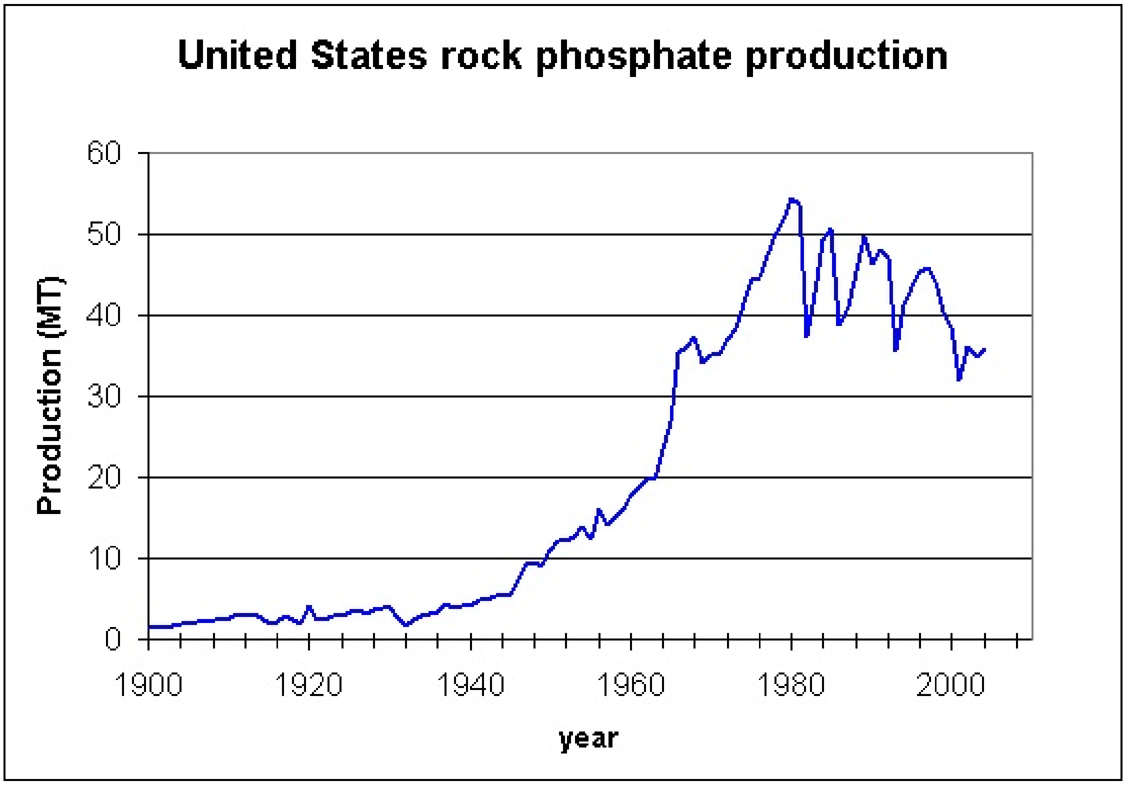


We see that the Hubbert Linearization just before peak, with this data set, exaggerated the URR (+26%) but the peak date (1978) was not so different from the real peak date (1973). It's the contrary for a H-L just after peak: the URR is slightly smaller (-6,5%) and the peak date is earlier (1971).

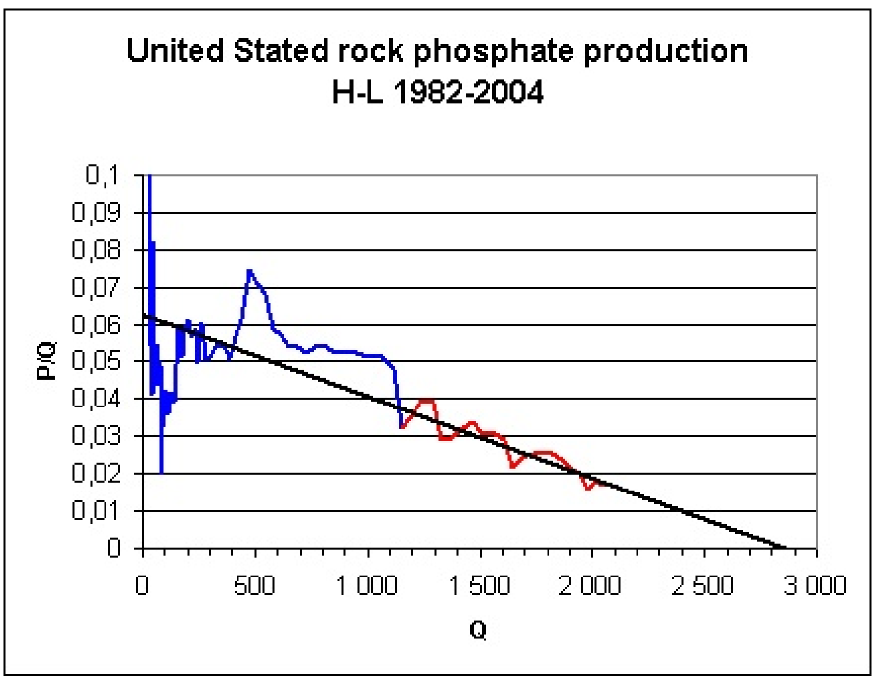
United States

The case of the United States is worth investigating since it is the "world's leading consumer, producer, and supplier of phosphate fertilizers," according to the USGS.

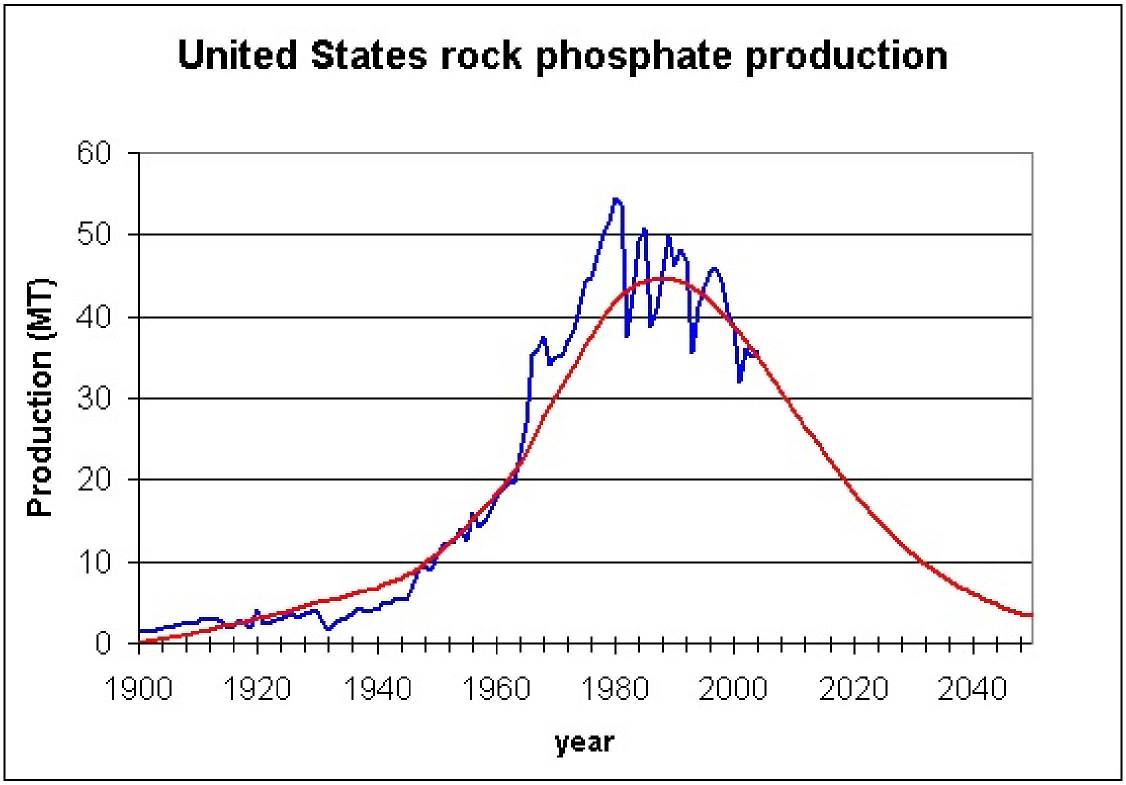
Plotting phosphate production for the United States, we obtain:



Using data from 1982 to 2004, we find an URR of 2850 MT.

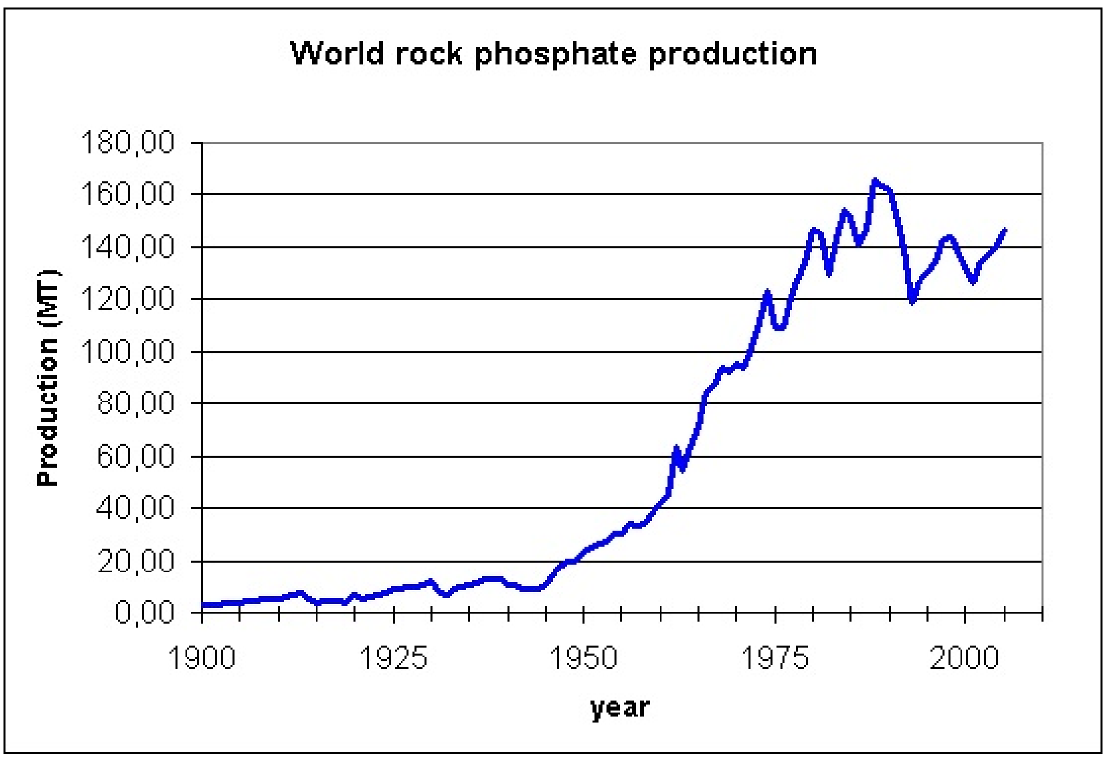


Calculating the production curve and plotting them with the real data gives us an estimated peak of 1988.

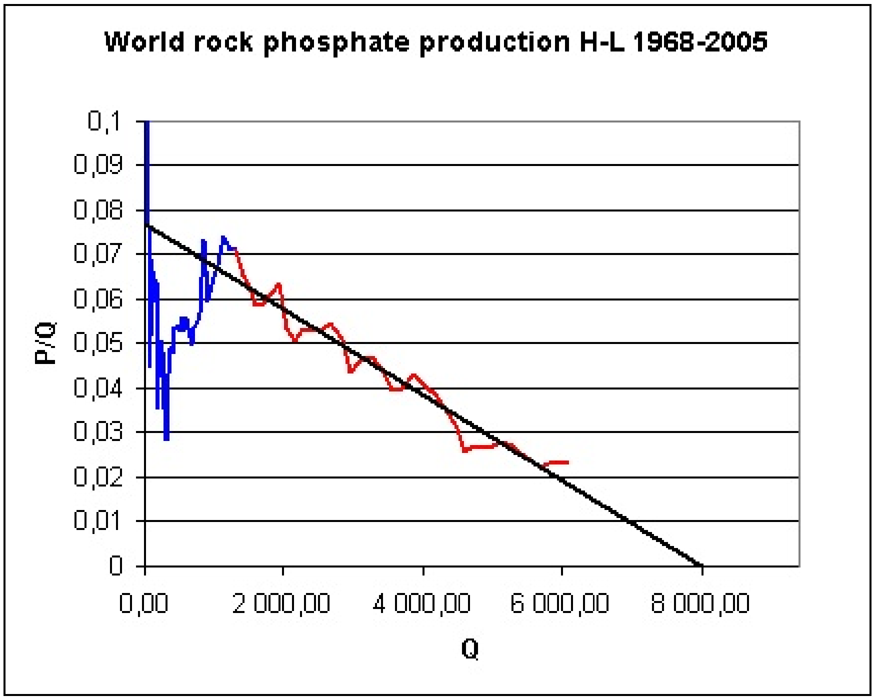


World production

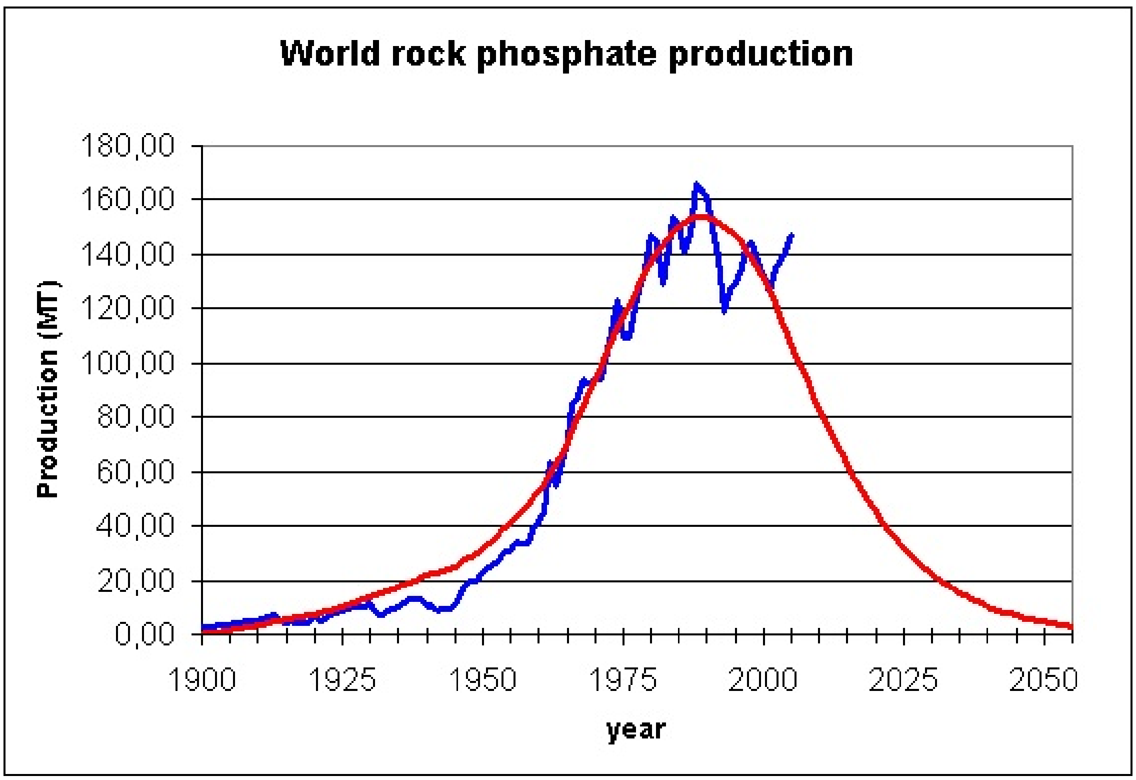
Plotting phosphate production for the world as a whole we obtain:



Using data from 1968 to 2005 reveals an URR of 8000 MT for the world as whole.



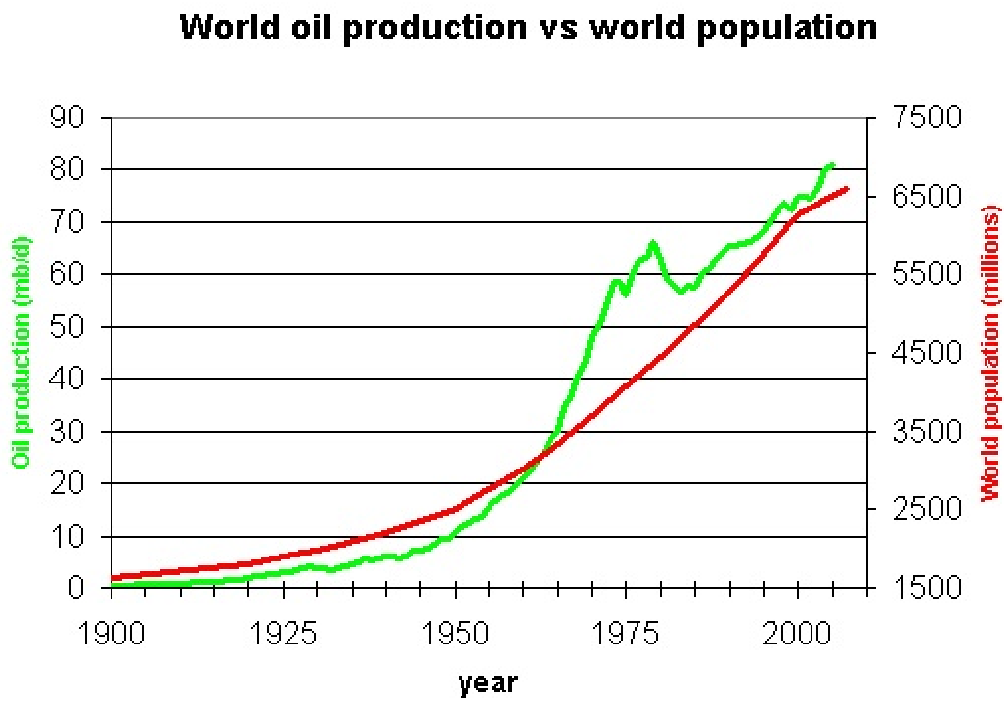
Calculating the production curve and plotting them with the real data:



We can see from the preceding graph that we are probably on a world decline of rock phosphate production.

Population and Phosphorus

Conventional agriculture uses vast amounts of oil and gas to produce food. We have just to plot data of world population versus world oil production to see the strong correlation between them.

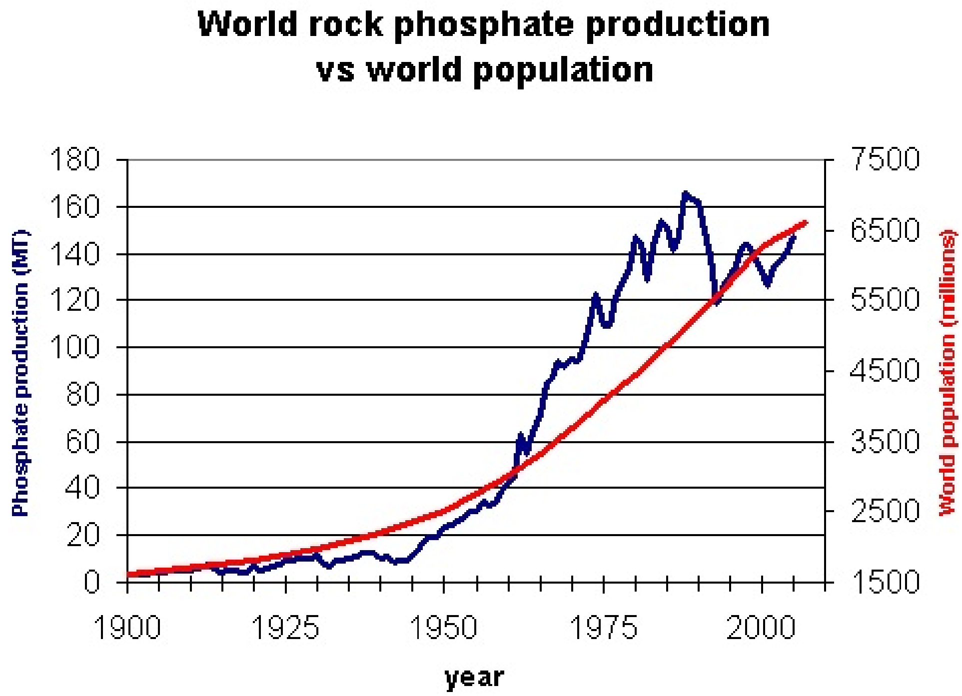


But oil production is not the whole story. Nutrients like nitrogen and phosphorus were also required for the "Green Revolution".

Nitrogen is present in large quantity in the atmosphere (78% of its composition). The Haber-Bosch process for obtaining nitrogen uses one percent of all energy consumed by humans [5]. Nitrogen can also be fixed in the soil using micro-organisms such as rhizobium and azotobacters. If there is sufficient energy, nitrogen will be available.

Phosphorus may be the real bottleneck of agriculture. [6]

Population growth was only possible because we found phosphorus deposits **and** cheap energy to extract, transform and transport it to farms. When we plot data of world population versus world phosphate production, we find a significant correlation.



What does this correlation mean? **Even if we find a real substitute for fossil fuels, it will be impossible to maintain population growth because phosphate deposits are probably in decline.** It will be impossible to maintain an agriculture without recycling nutrients.

Responses to Peak Phosphorus

In some ways, the problem of peak phosphorus is more difficult than peak oil. Energy sources other than oil are available, though they all have their own shortcomings. In addition, the sun provides a steady input of energy.

Unlike fossil fuels, phosphorus can be recycled. However if we waste phosphorus, we cannot replace it by any other source. Currently we are running through the limited supplies of concentrated phosphates. Phosphate fertilizer is often applied carelessly, leading to waste and pollution. Food from agriculture goes to consumers and animals, who excrete most of the phosphorus. The phosphorus in sewage mainly goes to sea or is otherwise dispersed.

The key response to a phosphorus peak is to re-create a cycle of nutrients. F.H. King in his classic *Farmers of Forty Centuries: Organic Farming in China, Korea and Japan* [4] describes how returning human and animal manure to the soil enabled Asian agriculture to continue to be productive for millenia.

Sewage sludge is one method now used for returning nutrients to agriculture, although there are safety concerns about the process. Other possibilities include:

- Composting toilets and composting of waste [7, 8, 9]

- Urine diversion [10, 11]
- More efficient application of fertilizer
- Technological innovations [2].

For more on the phosphorus problem, see Peak phosphorus: readings (Energy Bulletin).

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Patrick Déry is a "physicist, energy, agriculture and environment analyst and consultant in Quebec, Canada."

Bart Anderson is a former reporter, teacher and technical writer. He currently is co-editor of Energy Bulletin.

Patrick sent the original article to Energy Bulletin in April. I had never seen anyone apply the concepts of peak and Hubbert Linearization to phosphorus. Even though I had known intellectually that phosphorus supplies were limited, it wasn't until I read Patrick's paper that I realized how urgent the situation is.

To make Patrick's ideas more widely accessible, I added background information and did some wordsmithing, but all the original ideas are his.

For more background, see Peak phosphorus: readings (Energy Bulletin).

-BA