Closing the Loop on Closed Loop Reservoir Management*

Greg Walker[1], Linda Danard[1] and Shane Hallstrom[1]

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[1]Talisman Energy, Alberta, Canada (GXWALKER@talisman-energy.com)

Preface (Introductory Statements of Extended Abstract)

Reservoir simulation and history matching is generally used to identify infill targets and check how a secondary or tertiary recovery mechanism will affect the production profile. Since it is difficult enough to get a single history match in a manual process, the subsurface team cannot use a single result to generate a probability distribution function (pdf) and so the simulation is seen as a P50 or 2P estimate. The team can use the “P50” estimate to support a business decision, but reserves can only be used for depreciation when there is 90% confidence, and that means we need to get the probability distribution function. Further, we can only quantitatively calculate value of surveillance if we have an accurate estimate of both the current uncertainty and how we expect the new surveillance to change the result.

Closed Loop Reservoir Management is about running the reservoir to provide value for both production and information. Since it uses a numerical simulation of the reservoir, there is the potential for a quantitative value of surveillance and a means to explore the probability distribution function to check what the 1P reserves should be. The process can require significant computational resources, and typically the industry has the opinion that simulation does not add production, it is only wells and pressure support and tangible pieces of kit that do. However, the simulation can reveal targets, and can directly alter the cashflow and business model if we work on the P90 confidence of exceedance, used as 1P and therefore for reserves and DD&A.

Most prior studies on Closed Loop systems have included production optimization, with the passive acquisition of pressure and rate information to reduce uncertainty. The prior studies have not included active surveillance, such as seismic surveys and well production logging, or interference tests, and by making a quantitative case for how the surveillance will change the 90% confidence, and therefore depreciation and cashflow, both finding and making the business case for the optimal surveillance plan becomes quantitative. This is where the integrated subsurface team can really make a difference, as it is only in a shared reservoir model that the team can discuss quantitatively what future production profiles are allowed by a geological reasonable system and current surveillance constraints.

The economic value of reducing uncertainty is apparent from the DD&A benefit to accelerating reserves bookings. Even without changing the outcome, being able to provide evidence that an outcome is 90% likely to occur will improve the team's capability to make the resources into 1P reserves. This is critically important in a "grey physics" case where only some of the controlling parameters are known, such as unconventional reserves.

By providing a value to reducing uncertainty, and having a closed loop system to investigate surveillance options to reduce uncertainty, we can move beyond just looking for short term production rate and into long term value addition by optimizing the surveillance. However, there are certain barriers that must be overcome:

- Provide a reasonable estimate of the pdf of outcomes
- Tractable despite being a dual control problem
- Make a believable business case for investment

References

Walker, Greg J., Simon R. Bishop, Glyn J.J. Williams, Chris Reddick, 2007, Integration of Reservoir Planning and Surveillance - History to Prediction: International Petroleum Technology Conference, 4-6 December 2007, Dubai, U.A.E., Paper 11650-MS.

Walker, Greg J., and H. Scott Lane, 2007, Assessing the Accuracy of History-Match Predictions and the Impact of Time-Lapse Seismic Data: A Case Study for the Harding Reservoir: SPE Reservoir Simulation Symposium, 26-28 February 2007, Houston, Texas, U.S.A., Paper 106019-MS.

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Topics

- Assisted History Matching
- What can we do if we only have a single history matched model?
  - What could we do with a range of models?
- Closed Loop Reservoir Management
- System Theory
- Value of Information
- Difference between mathematically correct and useful
- Strategies and Ideas
- Implications for the Bruges case study
- Conclusions

General concepts

- Any model will be wrong in some detail
  - Simulation cannot be at perfect resolution
  - Still have to populate cells between well control points
- The data to define a history match may not be perfect
  - We can measure pressure
  - Oil rate, or export quality gas rates should be high quality for the field – but frequently back allocated to wells
  - How accurately do we measure water production?
- It is accuracy in prediction that counts
  - A history calibrated model is a good starting point
  - Parameters are calibrated by surveillance, depending on the current depletion mechanism
  - Examples are untested portions of a field for infill, or gas flood after a water flood.
- There are plenty of small targets inside a field, looking at field optimization for reserves
  - Typically 2-5% of recovery (IPTC 11650)
- The only cost of accessing these is having an accurate enough model to prove the target exists
  - Trying to prove something at the 2% level requires accuracy at the 2% level
- How do we get there in a practical manner?

What is Assisted History Matching?

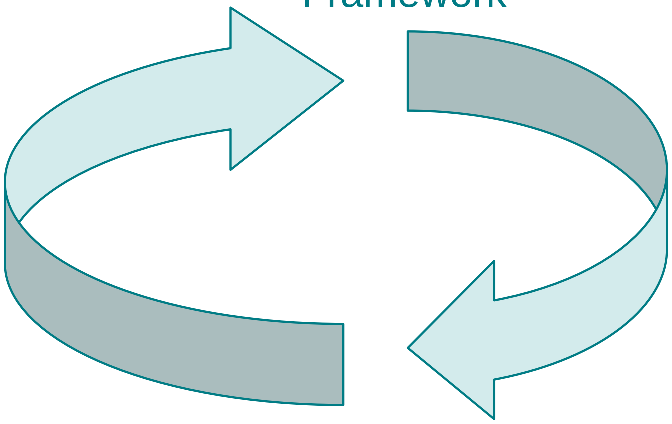
- Using a computer to search through a range of models
- The subsurface team defines what are acceptable uncertainties
    - Porosity trends, permeability trends, reservoir geometry within seismic and well control
- The subsurface team defines what is an acceptable history match
- Naïve users look for a faster route to a history match
    - Just changes the person-time required
    - No guarantee of a better prediction
- Automated system can look for alternative history matches quickly.

What is Assisted History Matching?

Subsurface
Framework

Optimization engine

Geology,
Geophysics
Reservoir
Engineer



Generate new realisation

How close is it to a history match?

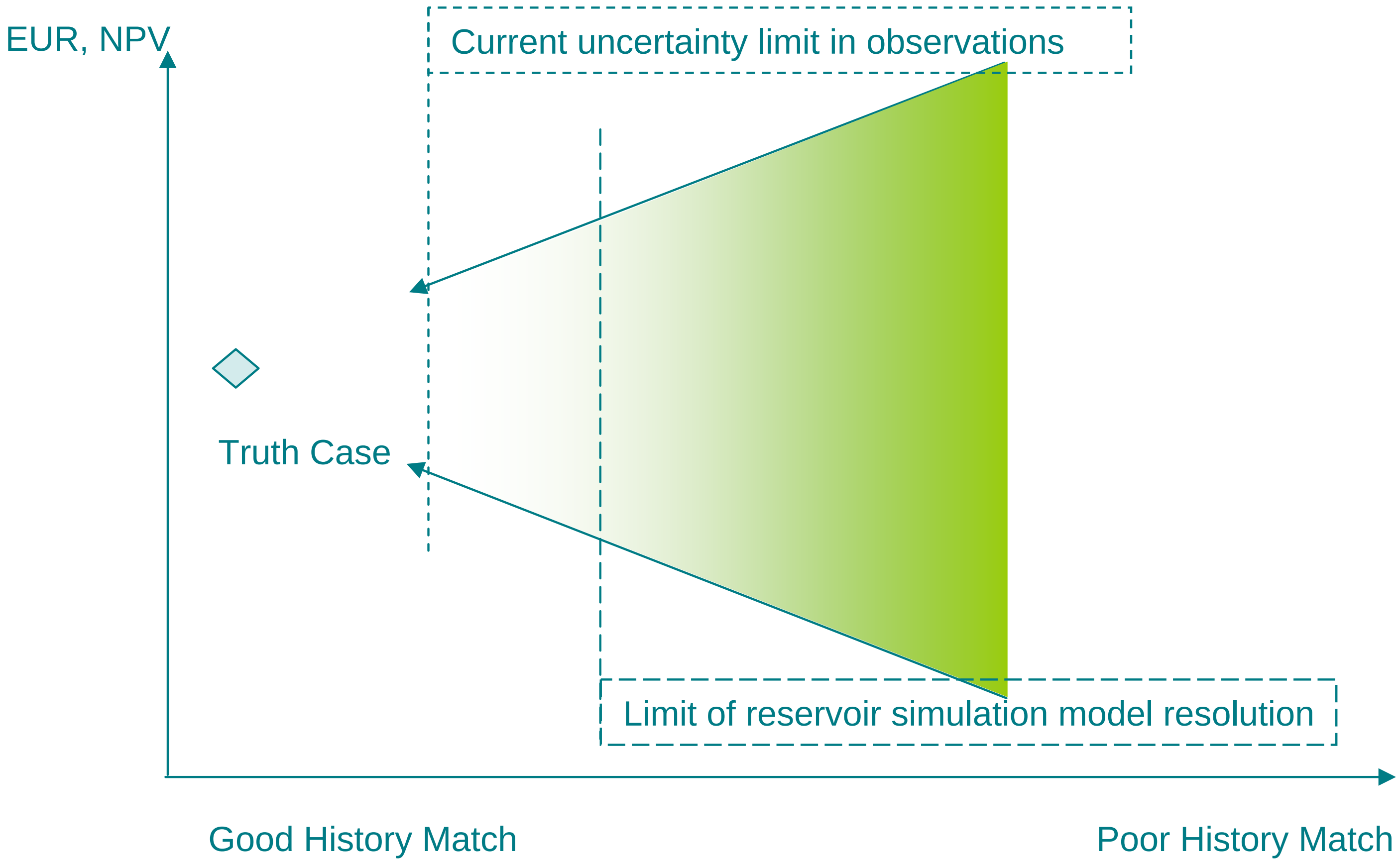
If all we have is a single model…

- Single estimate of future outcome, unable to determine probability
    - Most likely to be close to the P50, assuming normal distribution
    - Limits use of the reservoir model to defining 2P reserves

- How wrong could we be?
    - Models can fail to predict events in less than a year or 10% of reserves
    - SPE106019

- What are the implications?
    - Subsurface teams get locked into cycle of re-history matching

What can we do with multiple models?



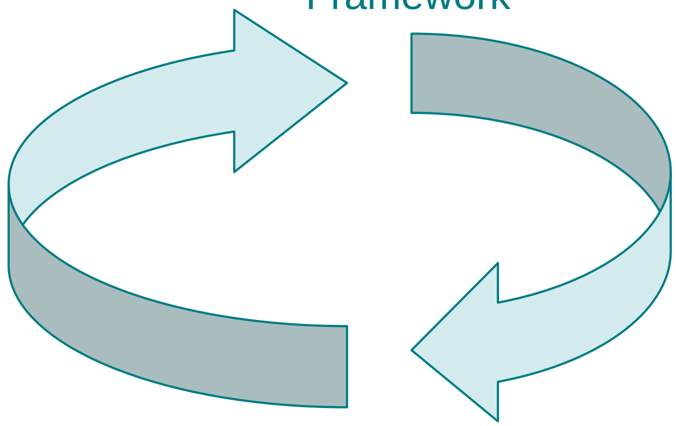
- Even if we have yet to identify the truth case
  - Can still determine likely EUR with greater confidence
  - Limits use of the reservoir model to defining 2P reserves

What is Closed Loop Management?

Subsurface Framework

Geology, Geophysics

Reservoir Engineer



Optimization engine

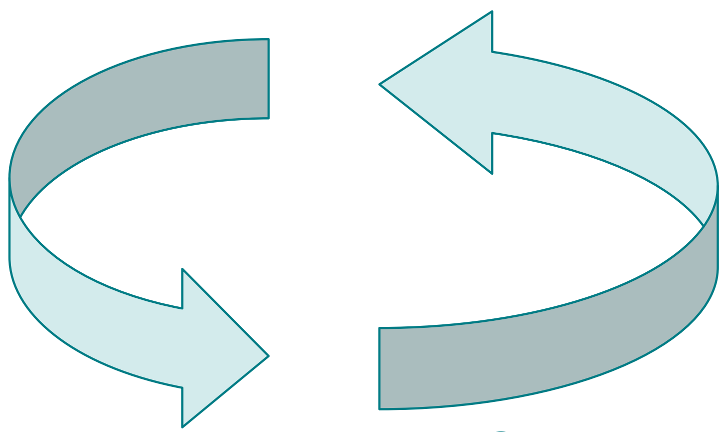
Generate new realisation

How close is it to a history match?

What is the best development option for the current range of models?

How accurately do I need to predict the future to justify the development?

What is the surveillance we need to acquire to improve prediction accuracy?



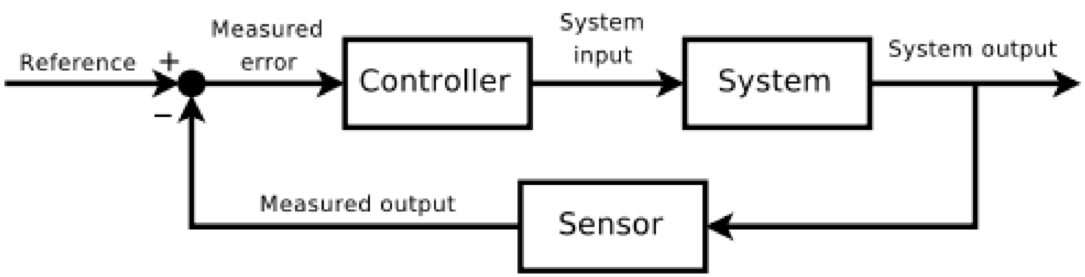
Optimization engine

Generate new surveillance plan

System Theory

- “Grey Physics Problem”
  - Some parameters are known, but not all
  - Unable to reset and restart

- “Dual control problem”
  - Optimising for both value delivered and for information
  - May be in conflict
  - Mathematically impractical to achieve
  - Impossible to achieve for a grey physics problem

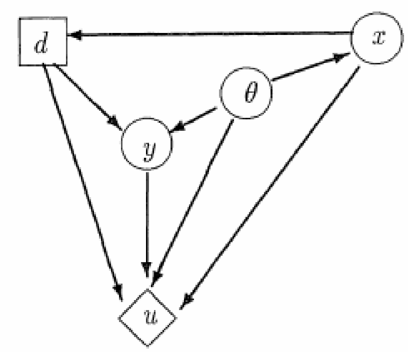


Theoretical Value of Information

Write the problem as a decision analysis problem

- use the Influence diagram theory (Matzkevich and Abramson – decision analytic network for artificial intelligence)
- x= previous information
- y = future information
- d = decision to take
- θ = unknown parameters

Figure 1 A generic influence diagram for our scheme.



$$\eta^* = \arg\max_{\eta \in N} \int_{Y} \max_{d \in D} \int_{\Theta} \left[u(\theta, d, x, y) - c(\theta, d, y) \right] p(\theta \mid y, x)\, d\theta\, p(y \mid x)\, dy$$

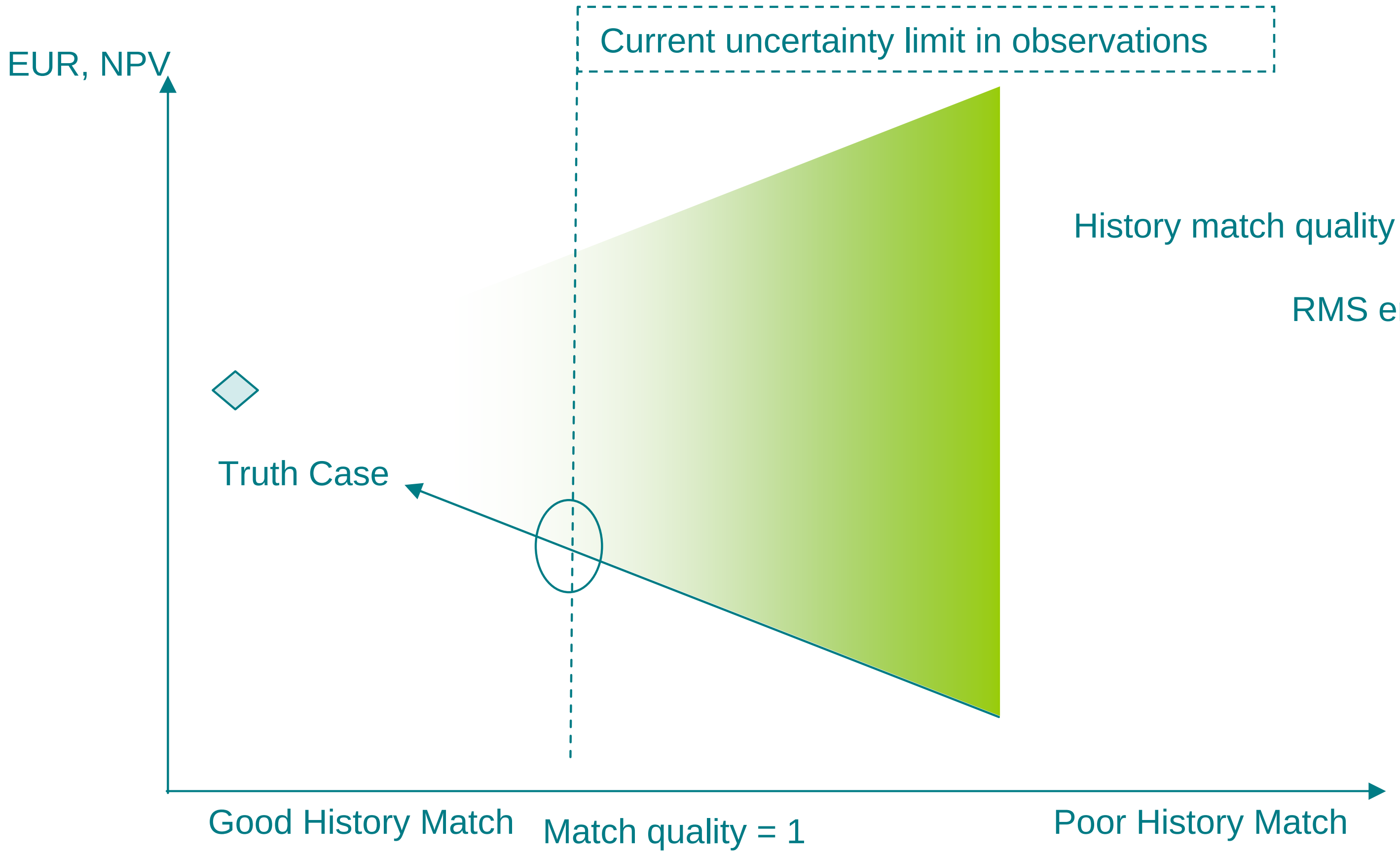
ANALYTICAL SOLUTION BUT with simplifying assumptions!:

- **<u>signals assumed costless</u>**
- signal probability invariant with time
- sunk costs invariant with time
- constant discount rate
- revenues treated as perpetuities.

So what do we need to do?

- Define a value of information that can be
  - Explained to a manager
  - Believed by a subsurface team
  - Implemented as an algorithm
- Define strategies to balance information gathering and production optimization
- Create a feedback cycle that is practical and economic

Defining a proxy for value of information



History match quality is defined as

RMS error / σ in observations.

So the gradient in the lower line yields a relationship between σ and the rate of improvement in the P90 (1P) estimate

$$\frac{\text{d Reserves}}{\text{d HMQ}} \times \text{d HMQ} = \text{d Reserves}$$

The cashflow DD+A can be approximated by

$$\text{Benefit} = \frac{\text{Total Capex}}{\text{RLI}} \; \frac{\text{d Reserves}}{\text{d HMQ}} \times \text{d HMQ}$$

Defining Value of Information for multiple developments

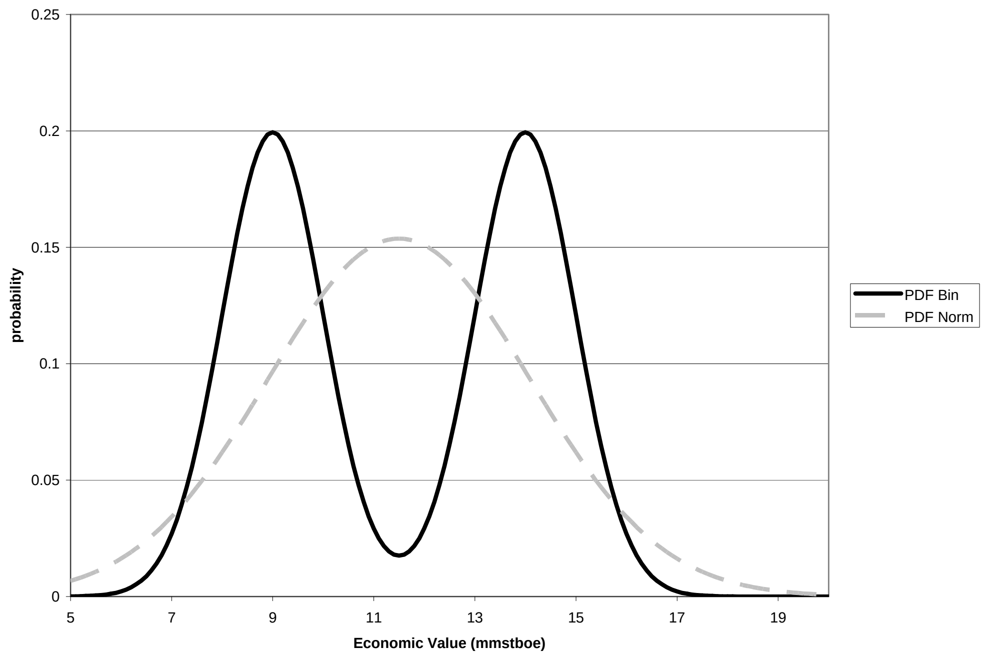
- Development option on a range of models is resource hungry
  - Combinations of models

- 3 model case
  - Optimize on model 1, or model 2, or model 3
  - Optimize on models 1+2, 1+3, 2+3
  - Optimize on models1+2+3 for a robust development

- Prior case study:
  - IPTC 11650
  - Production optimization on a model can add 2-5% reserves if the model is true
  - If the optimization is on the wrong model, can lose reserves

Bimodal or structure in the PDF

- Needs a simpler route to attack the problem
- For a base case development, can define the PDF of the outcome
  - EUR or NPV
  - Can look for structure to group models



SPE 106019

Defining strategies

- If the PDF shows local clusters
  - Then the models are clustering
  - Can treat as branching decision tree
  - Focus should be on surveillance

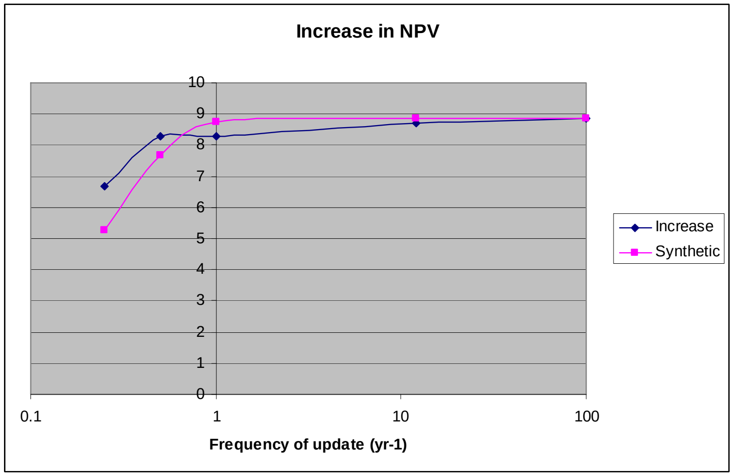
- Else
  - Just looking for improvements in the 1P reserves
  - Focus should be on production

Frequency of updating, value of strategy

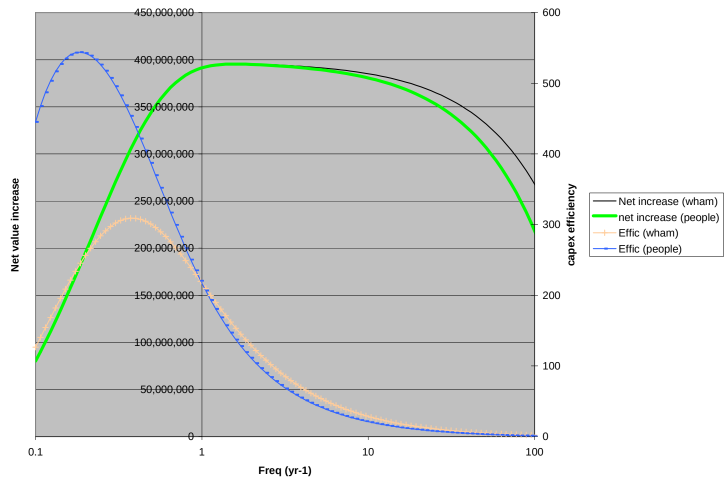
- E-Field, Smart Field
  - Looking at short term optimization
  - Reducing slug flow in wells, pipelines
  - Allocation of gas lift
  - Changing flow rates on a fast basis, reservoir responds to average flow rate
  - Vendors talking about data every second
- Pattern flood optimization
  - Long term, based on the accurate reservoir model being updated
  - Should also be a longer term cycle for updates

SPE-ATW Bruges case study

- NPV(open loop)* tanh(2.5(log(f)+1))



- Assume looking for a pattern balance prize
  - No capex, just software + surveillance
  - 1000 computer days to explore the PDF each time
  - $4.5bn NPV
  - Leads to an update frequency 2/yr
- Matches frequency of Life of Field Seismic installations



Discussion

- Closed Loop Reservoir Management
  - Provides a tool for quantitatively evaluating effect & value of surveillance
  - Should be looking for a 1P reserves prize, especially in complex/grey physics problems such as unconventional or fractured reservoirs
- Is a tractable problem with some thought
- Requires a lot of computer power
  - But not too much
  - Pays back due to being the only cost of entry to unlock 2-5% increase
  - May still be updating once year for accuracy, but generating multiple models