Linking Risk and Uncertainties to Field Development Planning In Challenging Environments

Stephen S. Kuo
BP plc
Primary funding is provided by

The SPE Foundation through member donations and a contribution from Offshore Europe

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Linking Risk and Uncertainties to Field Development Planning In Challenging Environments

Stephen S. Kuo
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Outline

• Context

• A Systematic Approach for Risk and Uncertainties Assessment

• Activity Plan for Uncertainty Reduction and Contingency

• Field Development Planning Examples

• Summary
Complex Geology Coupled with Complex Development Scheme Means…

... hundred’s million barrels of reserve is required to justify the development
Too Optimistic or Too Pessimistic…?

Key to Resource Estimate:
- Hydrocarbon Initial In-Place (HIIP) Volume
- Recovery Factor/Recovery Mechanism
- Well Productivity

Needs to articulate risk and uncertainties to enable an informed decision by the key stakeholders.
Terminology

• **Risk**: An event (or set of circumstances) that, should it occur, would have a material effect on the final value of a project
  – Characterized by *description* of the event, *probability* of occurrence and *impact* if it occurs
  – Impact can be positive as well as negative

• **Uncertainty**: a range of possible values or outcomes, resulting from imperfect knowledge
A Systematic Approach

• Identify risks with a subsurface root
  – Risk ranking matrix
• Link risk to key subsurface uncertainties
• Assess impact of uncertainties
• Develop an activity plan
• Communicate
<table>
<thead>
<tr>
<th>Risk Description</th>
<th>Impact</th>
<th>Probability of Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrocarbon In-Place - Fluid contact shallower than expected resulting in less than expected in-place volume</td>
<td>Low</td>
<td>Very Low: 1, Low: 2, Medium: 3, High: 4</td>
</tr>
<tr>
<td>Highly compartmentalized reservoir leads to rapid rate decline resulting in field plateau not delivered</td>
<td>Low</td>
<td>Very Low: 5, Low: 6, Medium: 7, High: 8</td>
</tr>
<tr>
<td>Weak aquifer support leads to rapid pressure decline resulting in reserve promise not delivered</td>
<td>Low</td>
<td>Very Low: 9, Low: 10, Medium: 11, High: 12</td>
</tr>
<tr>
<td>Poor reservoir quality in FB1...</td>
<td>Medium</td>
<td>Very Low: 13, Low: 14, Medium: 15, High: 16</td>
</tr>
<tr>
<td>FB2 has been severely depleted...</td>
<td>Medium</td>
<td>Very Low: 17, Low: 18, Medium: 19, High: 20</td>
</tr>
<tr>
<td>Southern Block has been depleted...</td>
<td>Medium</td>
<td>Very Low: 21, Low: 22, Medium: 23, High: 24</td>
</tr>
<tr>
<td>Perched water in FB3...</td>
<td>Medium</td>
<td>Very Low: 25, Low: 26, Medium: 27, High: 28</td>
</tr>
<tr>
<td>Exploration success...</td>
<td>Medium</td>
<td>Very Low: 29, Low: 30, Medium: 31, High: 32</td>
</tr>
<tr>
<td>Higher than expected drainage...</td>
<td>Medium</td>
<td>Very Low: 33, Low: 34, Medium: 35, High: 36</td>
</tr>
<tr>
<td>Sand production...</td>
<td>Medium</td>
<td>Very Low: 37, Low: 38, Medium: 39, High: 40</td>
</tr>
<tr>
<td>Wax and scale formation...</td>
<td>Medium</td>
<td>Very Low: 41, Low: 42, Medium: 43, High: 44</td>
</tr>
<tr>
<td>Water production...</td>
<td>Medium</td>
<td>Very Low: 45, Low: 46, Medium: 47, High: 48</td>
</tr>
</tbody>
</table>

**Key to Risk Description: Cause & Impact**

1. Mitigation (and Contingency)
2. Accept
Linking Risk to Uncertainties
(Hydrocarbon In-Place)

<table>
<thead>
<tr>
<th>Risk</th>
<th>Driver</th>
<th>Uncertainties</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Well H</td>
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<tr>
<td></td>
<td></td>
<td>Net Sand Distribution</td>
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<tr>
<td></td>
<td></td>
<td>Vertical Continuity</td>
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<tr>
<td></td>
<td></td>
<td>NTG</td>
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<td></td>
<td></td>
<td>GRV</td>
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<td></td>
<td></td>
<td>Pore Volume</td>
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<tr>
<td></td>
<td></td>
<td>Reservoir Base Surface</td>
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<td>Reservoir Top Surface</td>
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<td></td>
<td></td>
<td>Fluid Contact</td>
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<td>Net Pay</td>
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<td></td>
<td></td>
<td>Formation Thickness</td>
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<td>Vertical Sweep Efficiency</td>
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<td>Productivity Index</td>
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<td>Drawdown</td>
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<td></td>
<td>Drainage Efficiency</td>
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<td></td>
<td></td>
<td>Well initial Rate</td>
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<td></td>
<td></td>
<td>Well Decline Rate</td>
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<tr>
<td></td>
<td></td>
<td>Recovery Factor</td>
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<tr>
<td></td>
<td></td>
<td>Net Rock volume</td>
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<td></td>
<td>Net Pay</td>
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<td></td>
<td>Reservoir Top Surface</td>
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<td></td>
<td>Reservoir Base Surface</td>
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<td>Fluid Contact</td>
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<td>Net Sand Distribution</td>
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<td>Vertical Continuity</td>
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<td>NTG</td>
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<td></td>
<td></td>
<td>GRV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pore Volume</td>
</tr>
</tbody>
</table>

- Risk
- Driver
- Uncertainty (cannot be controlled)
- Decisions (can be controlled)
Linking Risk to Uncertainties (Compartmentalized Reservoir)

**Risk**
- Cost
- Resource
- Rate/Profile

**Driver**
- Opex Well
- Capex Well
- Drilling Schedule
- Recovery Factor
- Well Decline Rate
- Well Initial Rate

**Uncertainties**
- Step Out
- Drilling Time
- Rig Availability
- Compartmentalization
- Well Placement
- Drainage Efficiency
- Area Sweep Efficiency
- Displacement Efficiency
- Cut-off Efficiency Energy
- Drawdown
- Pressure
- Step Out
- Drilling Site Location
- Well Trajectories
- Well Placement
- Compartmentalization
- Faulting
- Fractures
- Production Well Count
- Heterogeneity
- Energy Displacement Efficiency
- Fractures
- Fault Location
- Fracture Connectivity
- Fracture Pore Volume
- Complex Wells
- Multi Lateral Wells
- Well Type
- Fault Transmissibility
- Fault Location
- Fracture Connectivity
- Fracture Pore Volume

**Legend**
- Risk
- Driver
- Uncertainty (cannot be controlled)
- Decisions (can be controlled)
Impact on HIIP

In-Place Volume = \( \text{area} \times \text{thickness} \times \text{ntg} \times \text{struc. uncert.} \times \text{por} \times \frac{1 - \text{Sw}}{\text{FVF}} \)

**Deterministic**

**Probabilistic**

Identify key parameters that have material impact
Impact on Dynamic Performance

Run a set of simulation cases using one-at-a-time change (parametric) or experimental design for reduced number of cases (statistical)
Impact on Well Productivity

Skin
Perm, md
Thickness, ft
Viscosity, cp
Bo, rb/stb

PI (stb/d/psi) or Well Rate (mbd)
### Deterministic Case Description

**Deterministic Model Description**

<table>
<thead>
<tr>
<th></th>
<th>Downside</th>
<th>Base Case</th>
<th>Upside</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Static Parameters</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net Rock Volume</td>
<td>Downside NRV map with LKO</td>
<td>ML NRV with ML OWC</td>
<td>Max NRV with ML OWC</td>
</tr>
<tr>
<td>Structure</td>
<td></td>
<td>Tied to Wells</td>
<td></td>
</tr>
<tr>
<td>Porosity, Swi, Boi and GOR</td>
<td>Average from all wells</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Dynamic Parameters</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aquifer volume</td>
<td>2x HCPV</td>
<td>4x HCPV</td>
<td>12x HCPV</td>
</tr>
<tr>
<td>Faulting</td>
<td>Worst Case</td>
<td>Base Case</td>
<td>Open</td>
</tr>
<tr>
<td>Sand connectivity</td>
<td>Heavy Baffles</td>
<td>Medium Baffles</td>
<td>Light Baffles</td>
</tr>
<tr>
<td>Horizontal Permeabilities</td>
<td>0.75x</td>
<td>1x upscaled Kx</td>
<td>1.5x</td>
</tr>
<tr>
<td>Kz/Kx multiplier</td>
<td>0.001x</td>
<td>0.1x</td>
<td>0.5x</td>
</tr>
<tr>
<td>Relative permeability</td>
<td>Low Rate</td>
<td>Base</td>
<td>High Rate</td>
</tr>
<tr>
<td>BHP, psia</td>
<td>High</td>
<td>ML</td>
<td>Low</td>
</tr>
<tr>
<td>Oil Viscosity, cp</td>
<td>MAX</td>
<td>ML</td>
<td>MIN</td>
</tr>
<tr>
<td><strong>Water Injection Scheme</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Injection target, mbd</td>
<td>0</td>
<td>32.5</td>
<td>64.5</td>
</tr>
</tbody>
</table>

“Deterministic” case so that its outcome can be related to actual performance
Deterministic cases vs. probabilistic outcome

Mapping deterministic cases to probabilistic outcome

- Un-risked Recoverable Resource (Probabilistic)
- Risked Recoverable Resource (Probabilistic)
- Reference Case
- Deterministic Sen. Cases

Plateau Length, Year

Recoverable Resources, bcf
Data Acquisition: key for reducing uncertainties

Well #1 → Well #2 → Well #3 → HC in Deep Sand

Success

Well #4 → Well #5

Failure

Well #4

Deep Sand Evaluation

• Res. Access
  - UMA5-10 (Sec.)
  - MMH10
  - LMH10/20/30
• Data Acquisition
  - Core (LM)
  - Static P
  - Fluid Samples
  - Logs+OBMI
• Flow Test
  - Test after Completion
• Interference test
• Issues
  - Depo Model
  - Res. Conn.
  - Fluid Prop
  - Is Ref case is a downside?
  • If so, re-evaluate Well #3 location

• Res. Access
  - UMA5-10 (Sec.)
  - MMH10
  - LMH10/20/30
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  - Core (MM)
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  - Fluid Samples
  - Logs+OBMI
• Flow Test
  - Test after Completion
• Interference test
• Issues
  - Depo Model
  - Res. Conn.
  - Fluid Prop
  - Is Ref case is a downside?
  • If so, re-evaluate Well #3 location
• If Successful
  - Complete in LMH30/40
• If Failed
  - Compete in LMH30 & LMH20

Resource Evaluation

• Res. Access
  - UMA5-10 (Sec.)
  - MMH10
  - LMH10/20/30
• Data Acquisition
  - Static P
  - Fluid Samples
  - Logs+OBMI
• Key driver for this well
  - MMH10 reserves
  - LMH20 reserves
• Timing
  - Risk of drilling into depleted zone

2nd Well for Deep Sand

• Res. Access
  - UMA5-10 (Sec.)
  - MMH10
  - LMH10/20/30
• Data Acquisition
  - Core (LMH40)
  - Static P
  - Fluid Samples
  - Logs+OBMI

Late Time Side Tracks f/Dev. Wells

• Un-drained resources separated by faults in
  - MMH10
  - LMH10/20/30

Resources with no risk

Resources with Risk

Late Time Side Tracks f/Dev. Wells
## Linking Uncertainties to Surveillance (Activity Plan)

<table>
<thead>
<tr>
<th>Key Risks/Uncertainties</th>
<th>Impact</th>
<th>Surveillance Activities</th>
<th>When will know</th>
<th>Contingency</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Oil-in-Place (Static)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand thickness</td>
<td>High</td>
<td>Logs evaluation and pressure/fluid sampling</td>
<td>Pre-drilling</td>
<td>1) Openhole sidetrack from development wells</td>
</tr>
<tr>
<td>Fluid Contact</td>
<td>Medium</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Recovery Factor (Dynamic)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aquifer strength</td>
<td>High</td>
<td>1) Interference test and/or pressure buildup after start-up</td>
<td>6 m after 1st oil</td>
<td>1) Pre-invest water injecting system, but drill water injector later</td>
</tr>
<tr>
<td>Faults/Compartmentalization</td>
<td>High</td>
<td>2) Surface and downhole P/T monitoring after start-up</td>
<td>6 m after 1st oil</td>
<td>1) Drill additional well or sidetrack, including high-angle or horizontal well across faults</td>
</tr>
<tr>
<td>Sand continuity/Facies Description</td>
<td>High</td>
<td>3) Logs evaluation</td>
<td>Pre-d &amp; 6 m after 1st oil</td>
<td>1) Alternate geological model 2) Inter-well connectivity test 3) Plan for infill drilling</td>
</tr>
<tr>
<td><strong>Well Productivity and Injectivity (Dynamic)</strong></td>
<td>Medium</td>
<td>1) Well test 2) Well performance evaluation</td>
<td>After 1st oil</td>
<td>1) Routine well test 2) Plan for well intervention program</td>
</tr>
</tbody>
</table>

Allow sufficient time for reservoir surveillance
Compartmentalized Reservoir

- **Risk**: Small compartment leads to rapid rate decline resulting in field plateau not delivered
- **Uncertainties**: Reservoir Connected Volume and Faults
- **Mitigation**: Reservoir Surveillance, Interference test, etc.
- **Contingency**: Plan for additional well
- **Risk Exposure in $$$**
Aquifer Strength

- **Risk**: Weak aquifer support leads to rapid pressure decline resulting in reserve promise not delivered
- **Uncertainties**: Aquifer size and connectivity

- **Mitigation**: Reservoir surveillance before injection starts
- **Contingency**: *Pre-invest* water injection system (space, weight allowance & slots), but install plant & drill wells only if surveillance shows lack of aquifer support
- **Risk Exposure in $$$**
Fluid Presence

- **Risk:** Fluid contact shallower than expected resulting in less than expected in-place volume
- **Uncertainties:** Hydrocarbon in-place volume

![Diagram](image)

- **Mitigation:** Plan development well to penetrate shallower known reservoir on the trajectory
- **Contingency:** Side-track updip for production
- **Risk Exposure in $$ $$
Summary

• A systematic approach to rank risks and assess uncertainties is discussed

• Linking risks to uncertainty parameters so that their impacts are assessed and understood

• It is important to communicate risk and uncertainties to key stakeholders so that an informed decision can be made

• Several examples on risk mitigation and contingency planning are presented
Key Take-away

• Keep it simple, only focus on key uncertainties that have material impact

• Evaluate and understand their impacts

• Link uncertainties to surveillance

• Define a few deterministic cases so that actual performance can be related to predicted outcome
Acknowledgements

• SPE Foundation for support of the Distinguished Lecturer program

• BP management for professional recognition and permission to participate in the SPE DL program

• BP colleagues who provided support to part of the work presented

• Local SPE chapters worldwide for hosting the presentations
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