Geostatistical Methods for Unconventional Reservoir Uncertainty Assessments*

Michael Pyrcz[1], Peter Janele[1], Doug Weaver[1], and Sebastien Strebelle[1]

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Abstract

New methods are required to support unconventional reservoir uncertainty modeling. Unconventional plays add additional complexity with greater uncertainty in direct reservoir measures (e.g. unreliable permeability measures in low permeability rock) and weakened relationships between currently measurable reservoir properties and production results (production mechanisms may not be well understood). As a result, unconventional plays are often referred to as “statistical plays”, suggesting the reliance on statistical characterization of production distributions as a function of well counts. The application of the techniques described herein can be utilized to integrate all available information to determine appropriate levels of drilling activity to reduce uncertainty to an acceptable level. Geostatistical approaches provide opportunities to improve the rigor in the dealing with statistical plays. Rigor is introduced through integration of methods that account for: representative statistics, spatial continuity, volume-variance relations and parameter uncertainty. Analog production data from US shale gas plays are utilized for demonstration. These data sets, after debiasing, are sources for analog production rate distributions and spatial continuity. Given, these statistics along with a decision of stationarity, geostatistical workflows provide repeatable uncertainty models that may be summarized over a spectrum of model parameters, drilling strategy and well counts. These geostatistical methods do not replace the need for expert judgment, but they improve the rigor of statistics-based approaches that are essential in statistical plays.

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AAPG 2017, April 2nd-5th, Houston Texas

Unconventional Reservoir Uncertainty Assessments

1. Introduction
2. Maximizing Use of Analogs
3. Direct Assessment of Block Uncertainty
4. Well Aggregate Uncertainty
5. Conclusions

Unconventional Reservoir Uncertainty Assessments

1. **Introduction**
   - Problem Setting
   - Previous Work
2. Maximizing Use of Analogs
3. Direct Assessment of Block Uncertainty
4. Well Aggregate Uncertainty
5. Conclusions

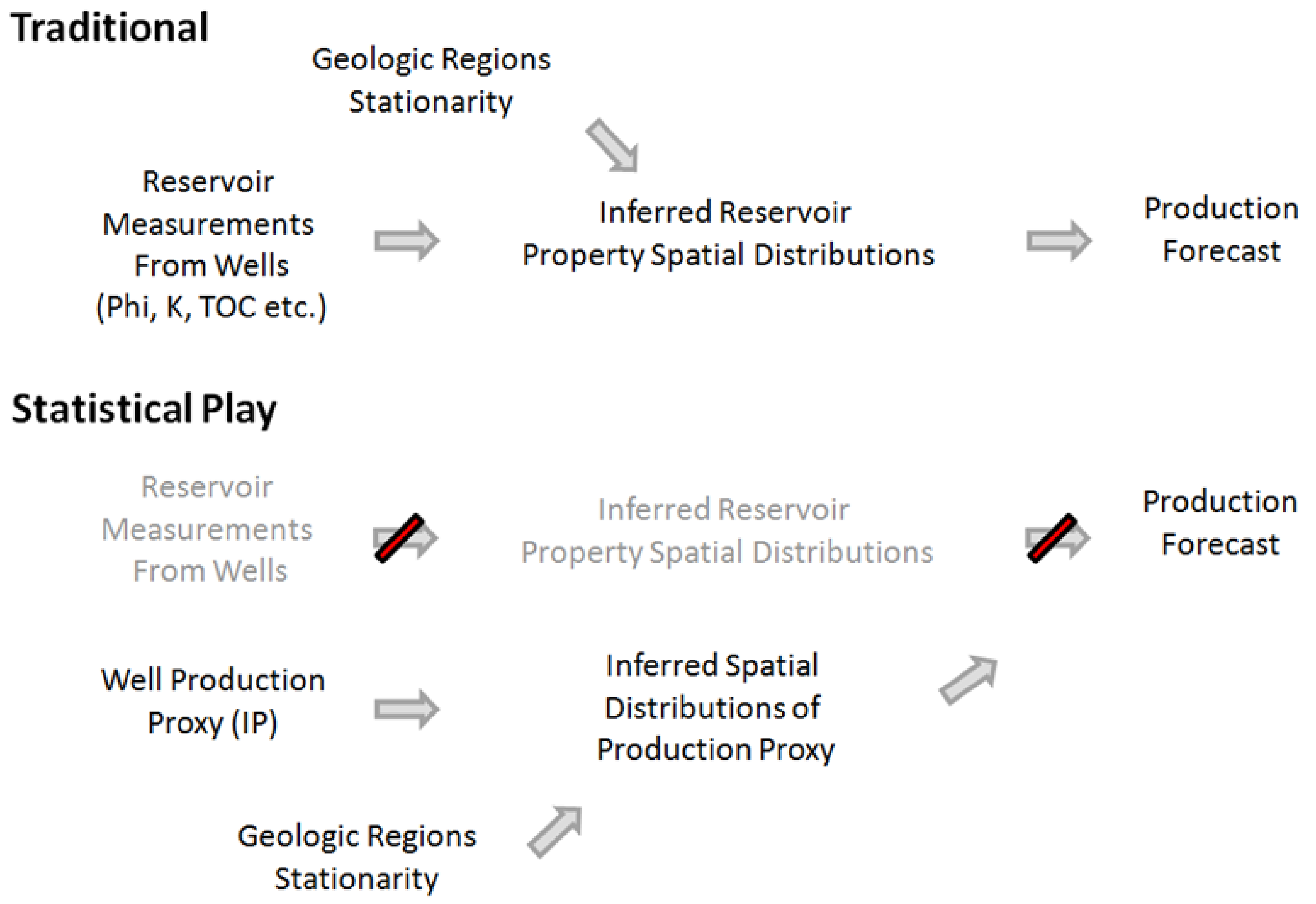
Introduction - Problem Setting

- Unconventional Shale Plays
  - **Tight** – nanoscale throats pore throats, challenged permeability assessment and flow mechanism (Sakhaee-pour and Bryant, 2012)
  - **Continuous** – extensive and poorly delineated (review of domestic shale gas datasets)
  - **More Multivariate** – add TOC, brittleness, vitrinite reflectance to the traditional (secrete sauce?)
  - **Resource Estimation** – volumetric-based approaches are not feasible (Olea et al., 2011)

New methods are needed.

Introduction - Problem Setting

- Traditional Approach
  - Infer reservoir properties at and between wells
  - Forecast with volume calculation and forward modeling of flow response
- Statistical Play
  - Reservoir property measurements are more uncertain
  - Reservoir property and production relationships are weakened.
  - Solution: directly model production.



Statistical play concept (Pyrcz and Deutsch, 2012).

Introduction - Opportunity

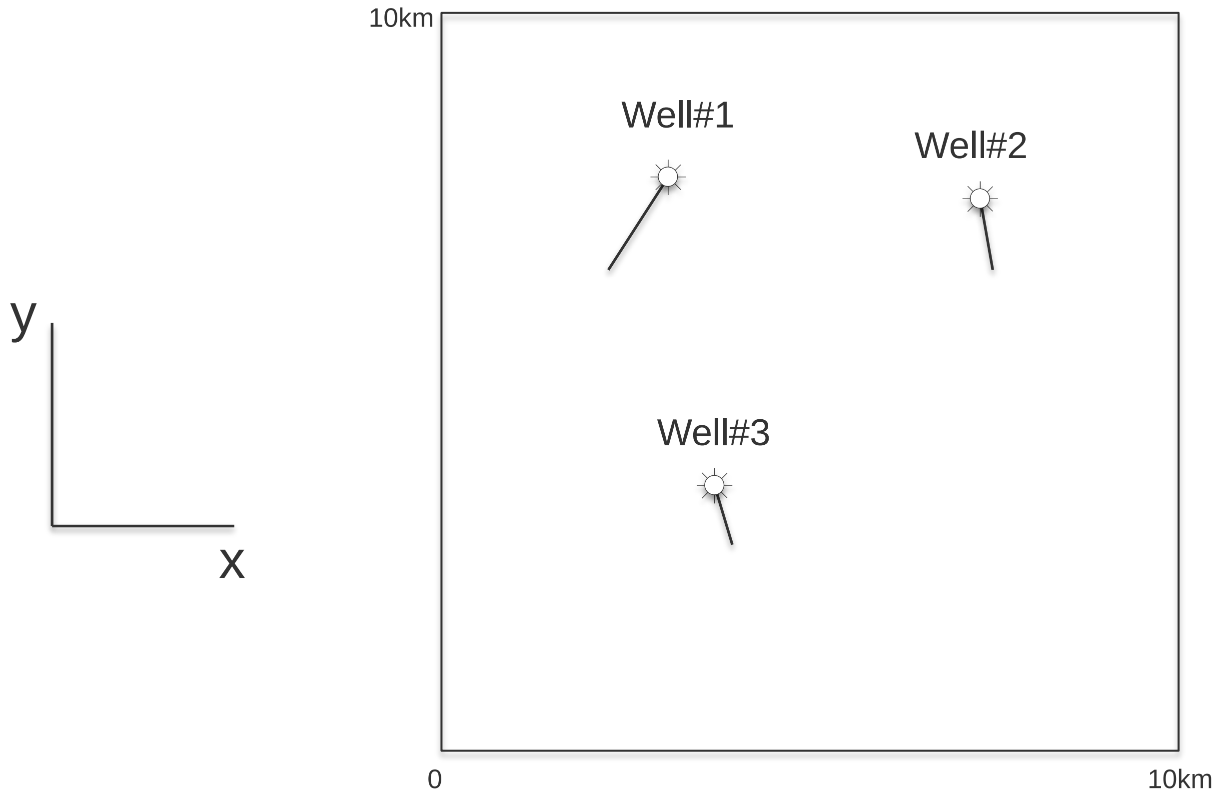
- Current Approaches
  - Direct modeling of well production (Estimated Ultimate Recovery) or proxy (initial production) (Schmoker, 1999)
  - Geostatistical simulation of production with secondary data (e.g. thickness and vitrinite reflectance) (Olea et al., 2011)
  - Uncertainty modeling based on bootstrap (SPEE, 2010)

- There are opportunities to:
  - Use geostatistical theory to add “spatial statistics” to the statistical play.
  - We build on the work of Olea et al.,(2011)

- Resulting Workflows:
  - **Model for shale block uncertainty** ➡ Range in performance? How would this change if new wells drilled?
  - **Model for well aggregate uncertainty** ➡ What is the uncertainty aggregated well results?

Introduction - Prerequisites

Geostatistical Simulation Approach (Olea et al., 2011)

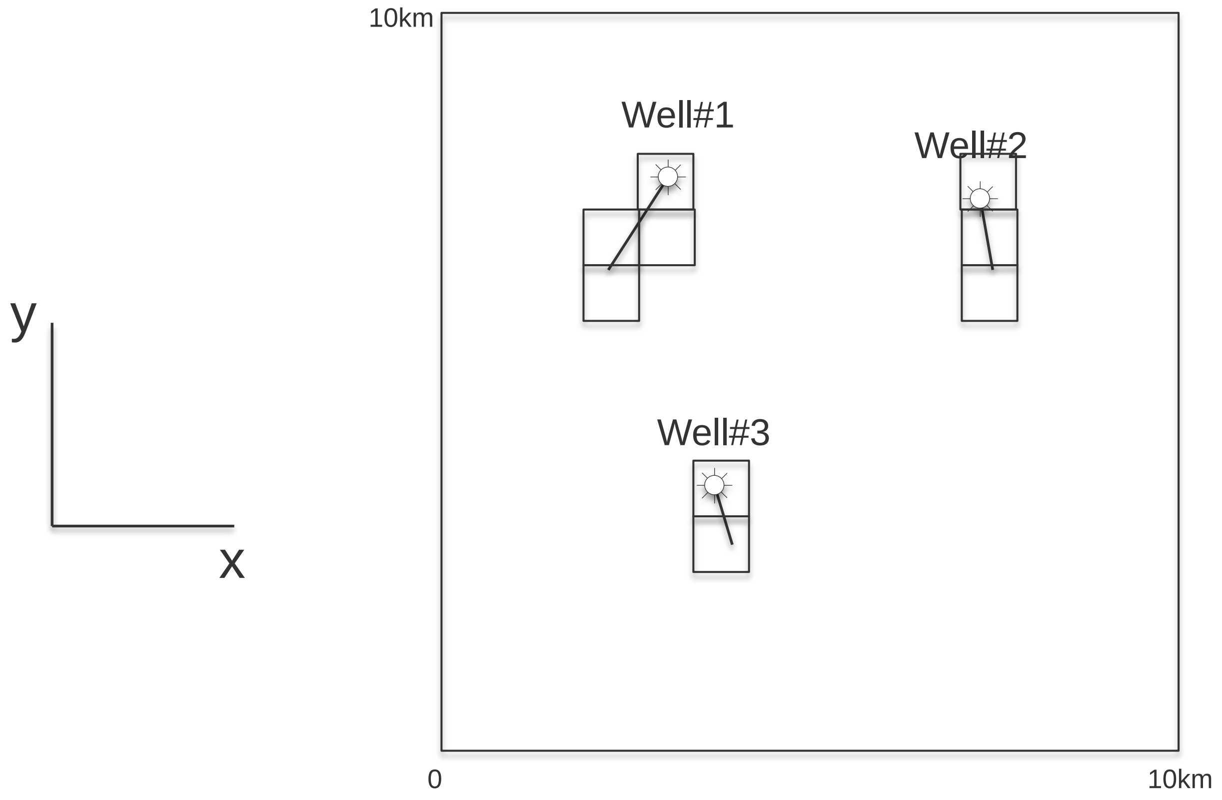


Simple synthetic shale reservoir

Introduction - Prerequisites

Geostatistical Simulation Approach (Olea et al., 2011)

1. Partition EUR over cells within drainage area.

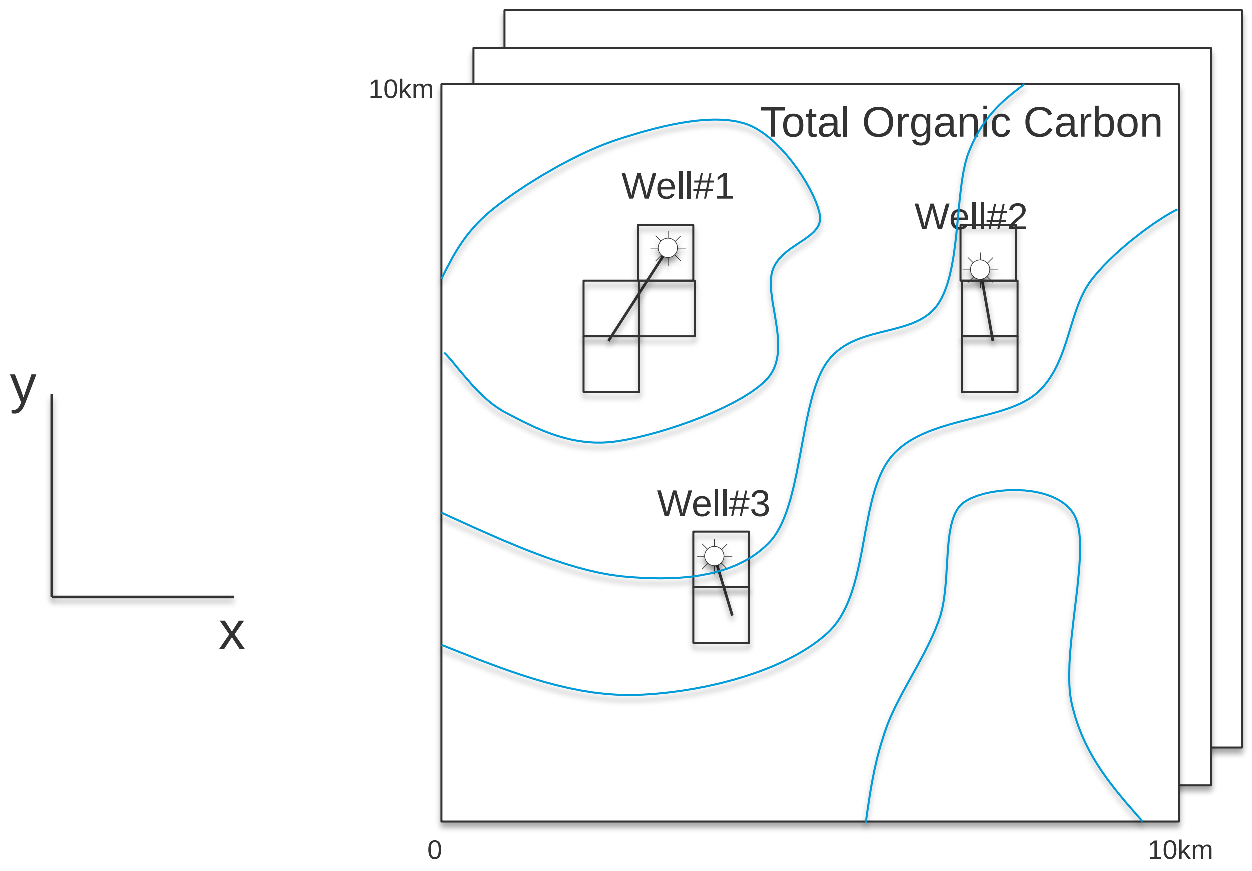


Simple synthetic shale reservoir

Introduction - Prerequisites

Geostatistical Simulation Approach (Olea et al., 2011)

1. Partition EUR over cells within drainage area.
2. Simulate secondary variables.

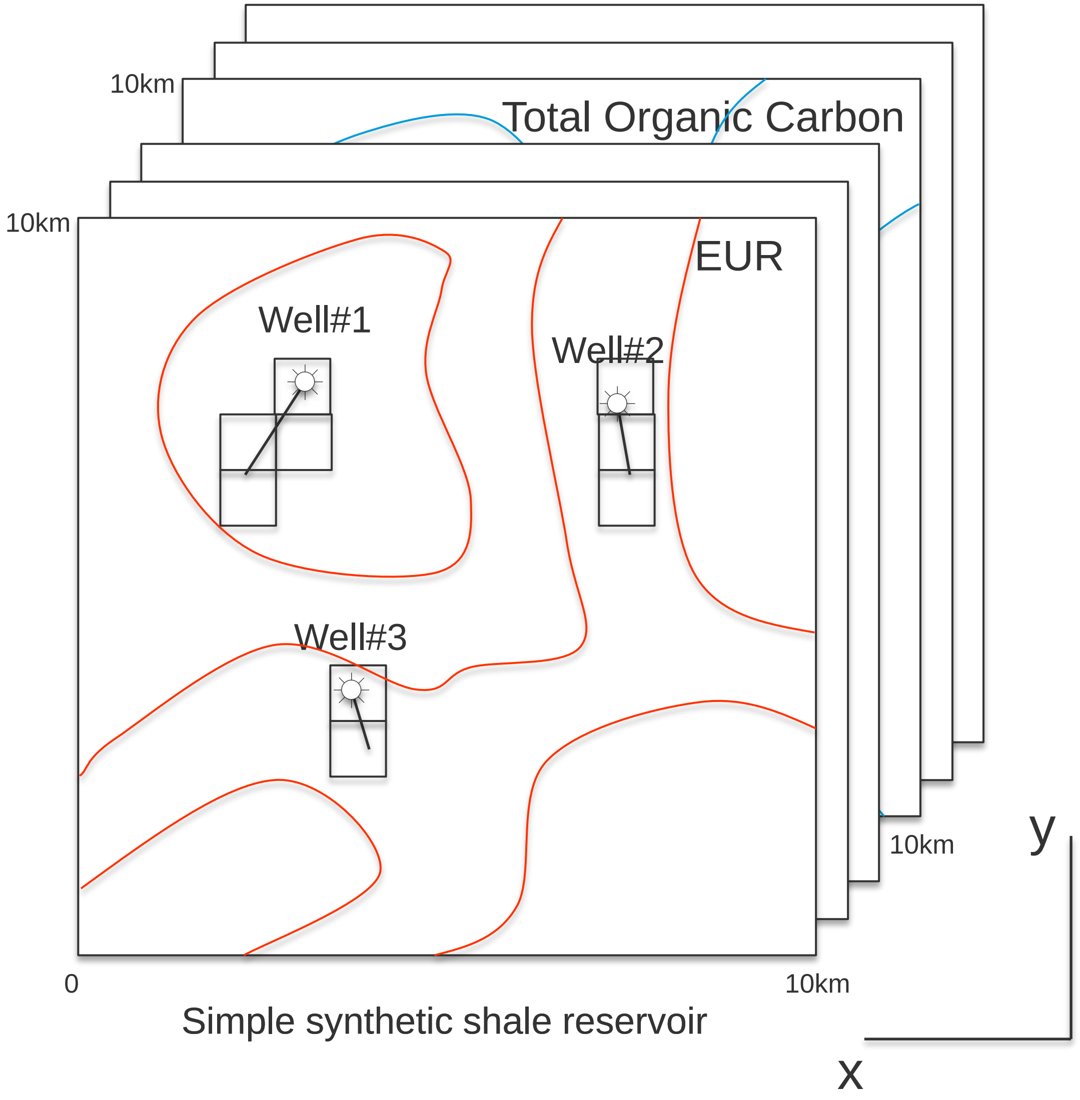


Simple synthetic shale reservoir

Introduction - Prerequisites

Geostatistical Simulation Approach (Olea et al., 2011)

1. Partition EUR over cells within drainage area.
2. Simulate secondary variable(s).
3. Cosimulate EUR constrained by secondary variable(s).

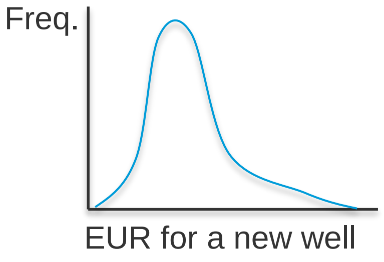


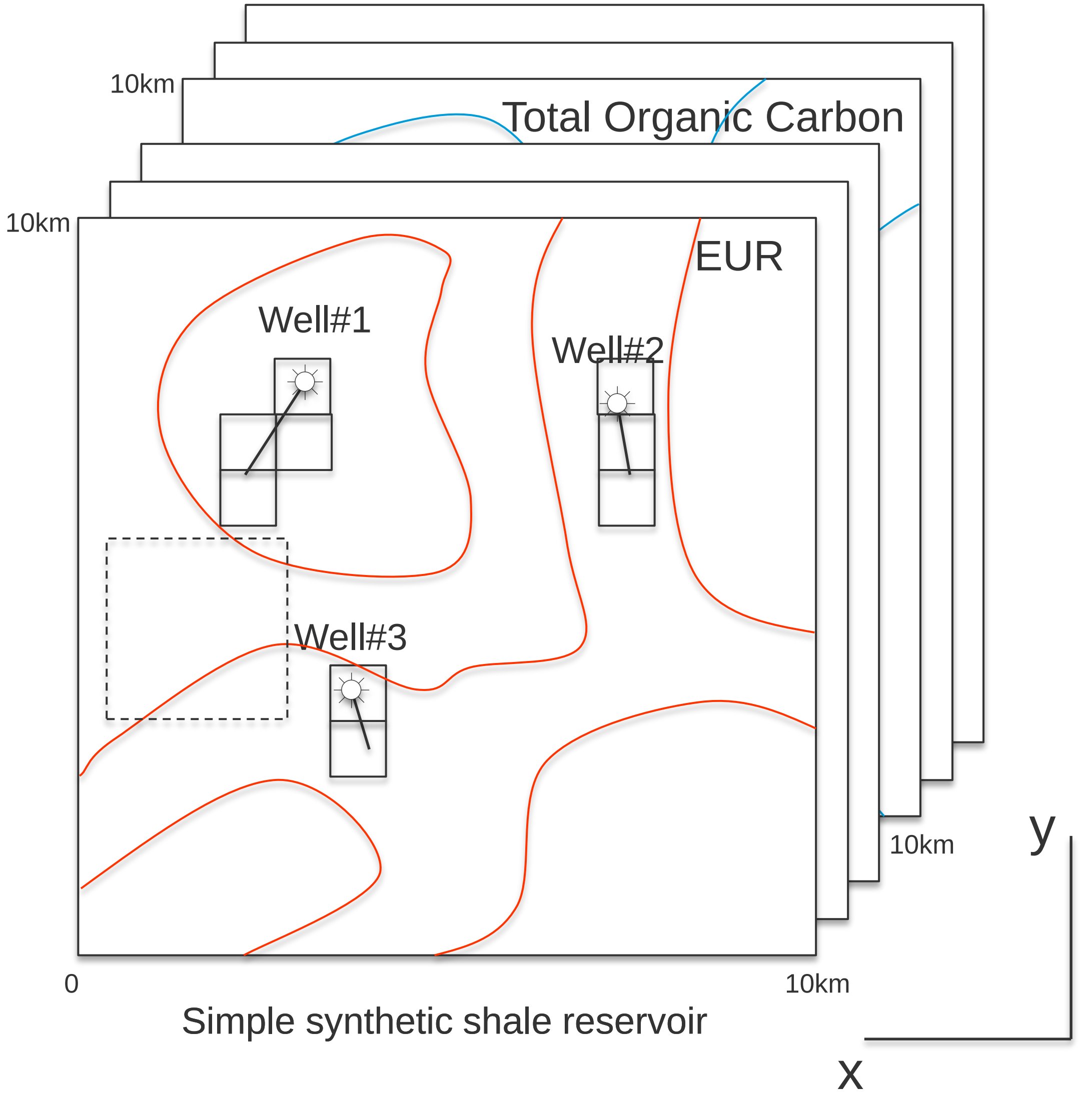
Simple synthetic shale reservoir

Introduction - Prerequisites

Geostatistical Simulation Approach (Olea et al., 2011)

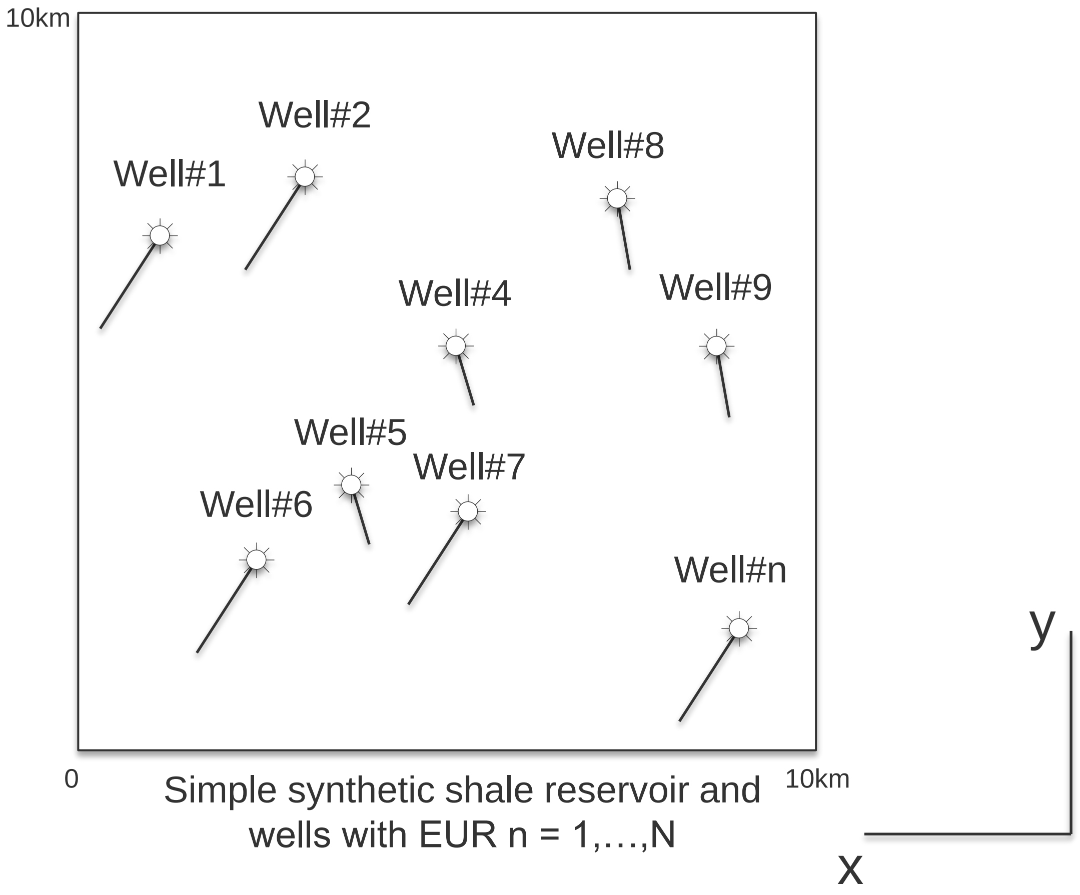
1. Partition EUR over cells within drainage area.
2. Simulate secondary variable(s).
3. Cosimulate EUR constrained by secondary variable(s).
4. Summarize simulated EUR over assessment area.





Introduction - Prerequisites

Bootstrap Approach (SPEE, 2010)

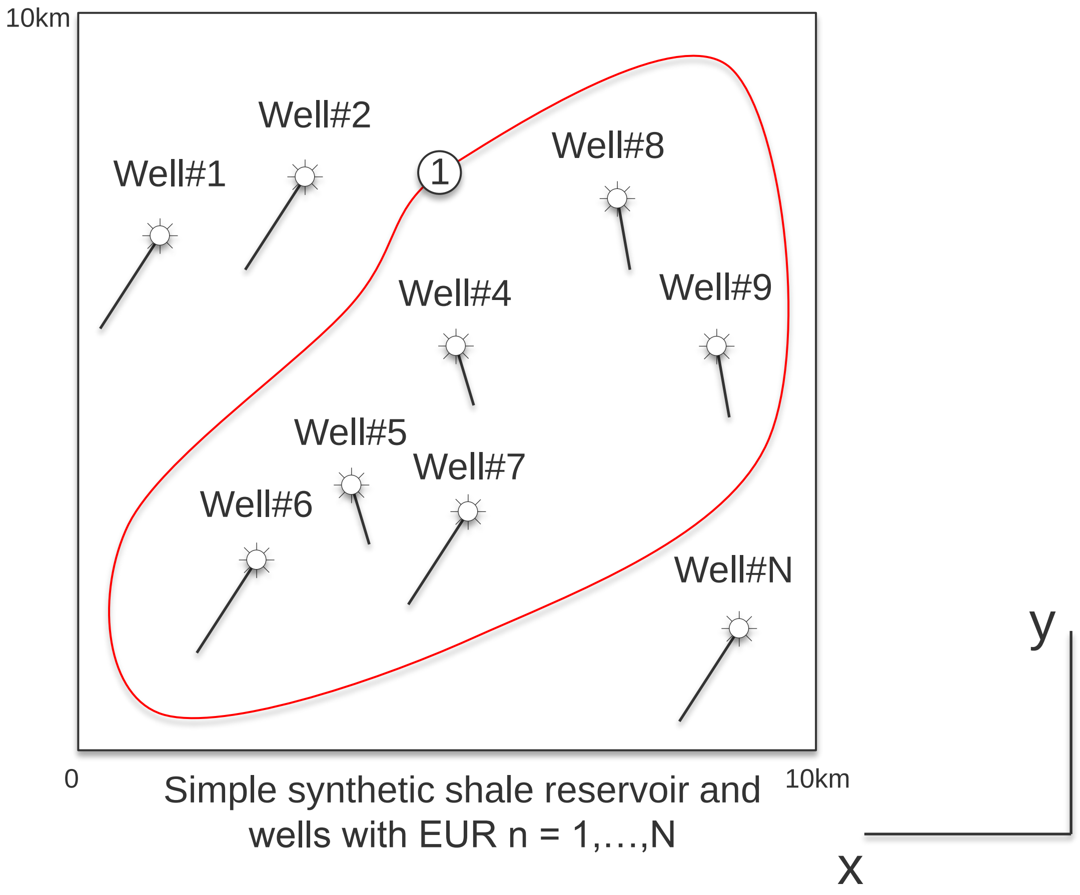


Simple synthetic shale reservoir and wells with EUR n = 1,…,N

Introduction - Prerequisites

Bootstrap Approach (SPEE, 2010)

1. Identify analogous wells

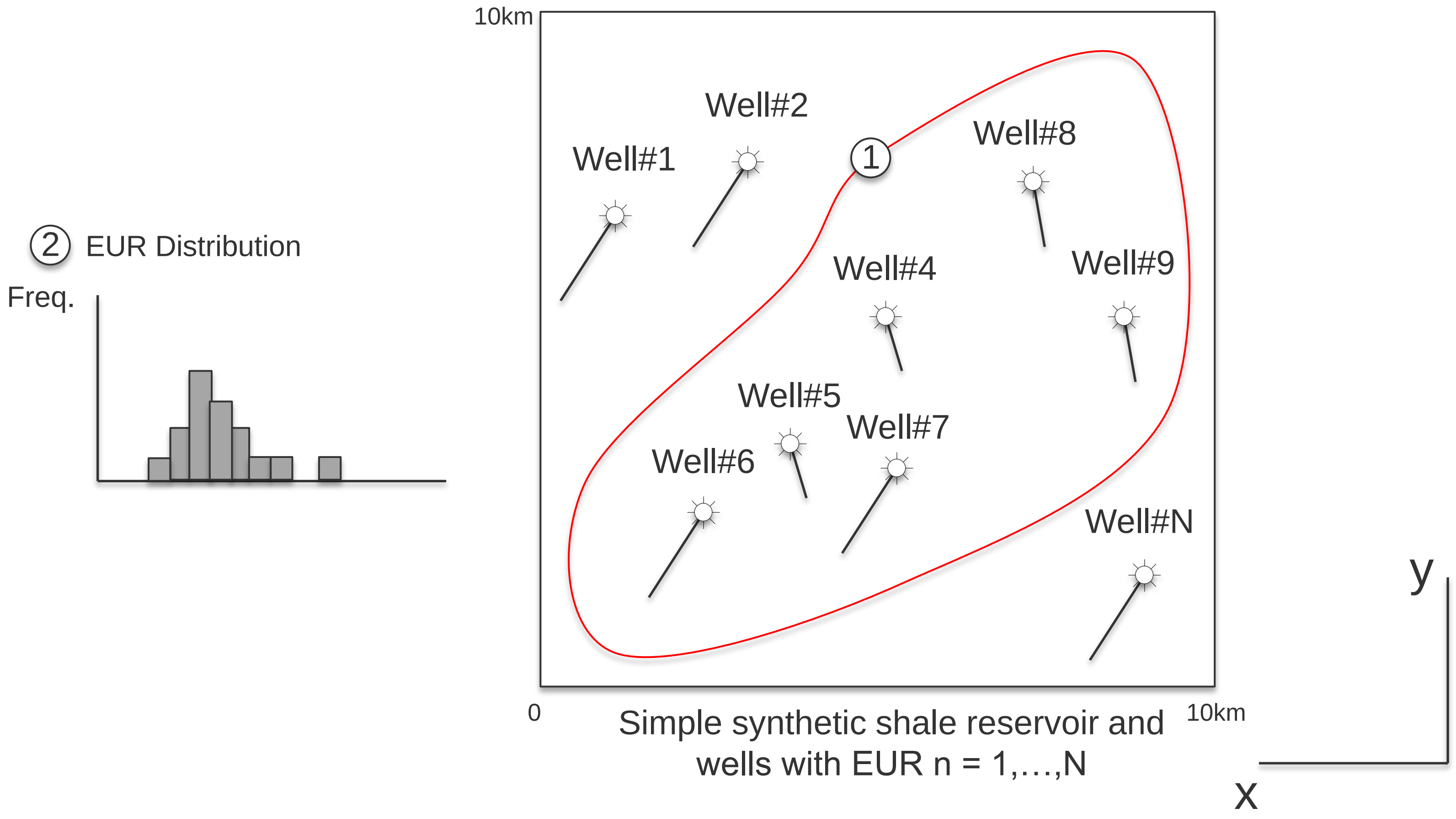


Simple synthetic shale reservoir and wells with EUR n = 1,…,N

Introduction - Prerequisites

Bootstrap Approach (SPEE, 2010)

1. Identify analogous wells
2. Model the EUR distribution

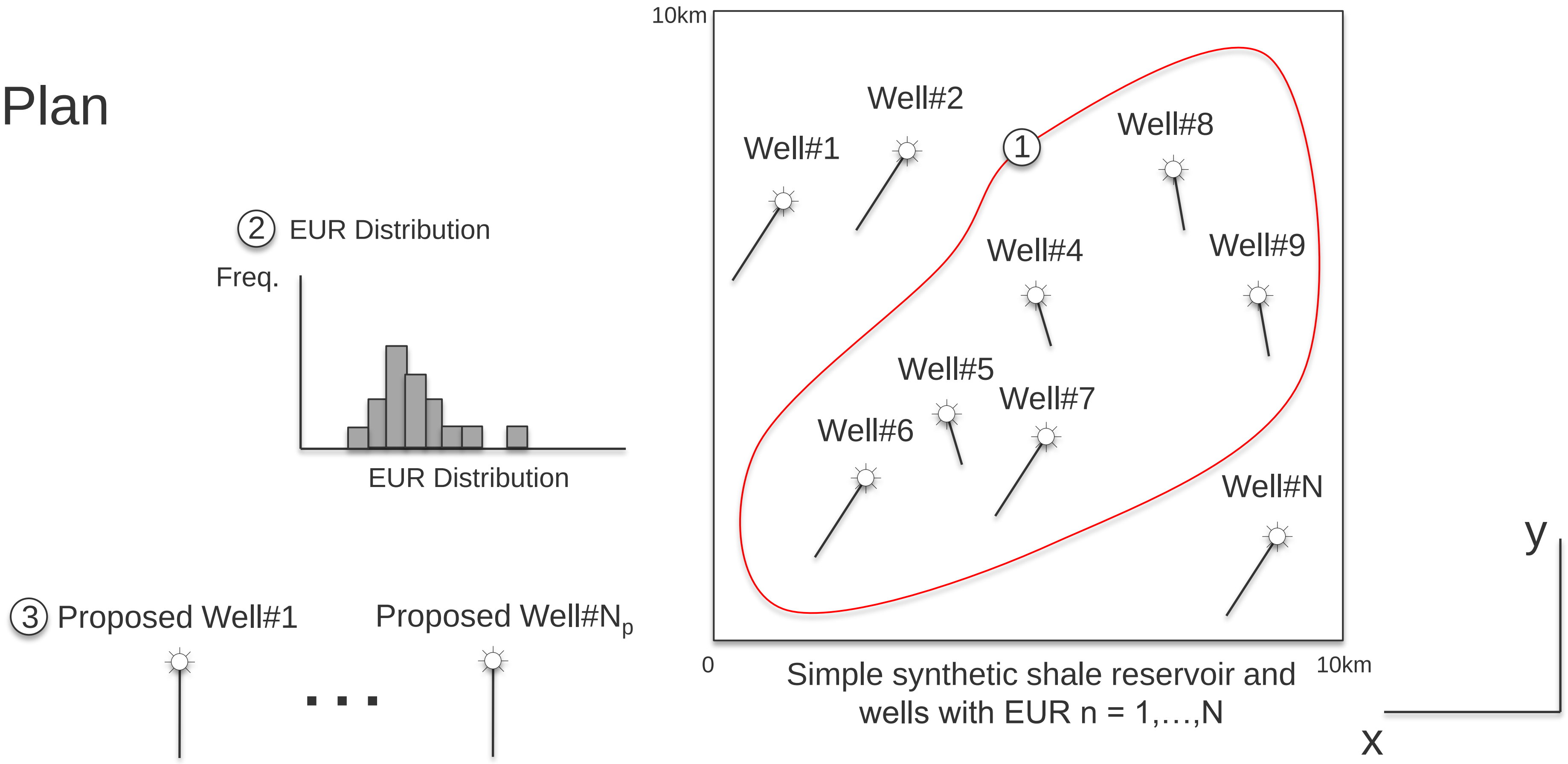


Simple synthetic shale reservoir and wells with EUR n = 1,…,N

Introduction - Prerequisites

Bootstrap Approach (SPEE, 2010)

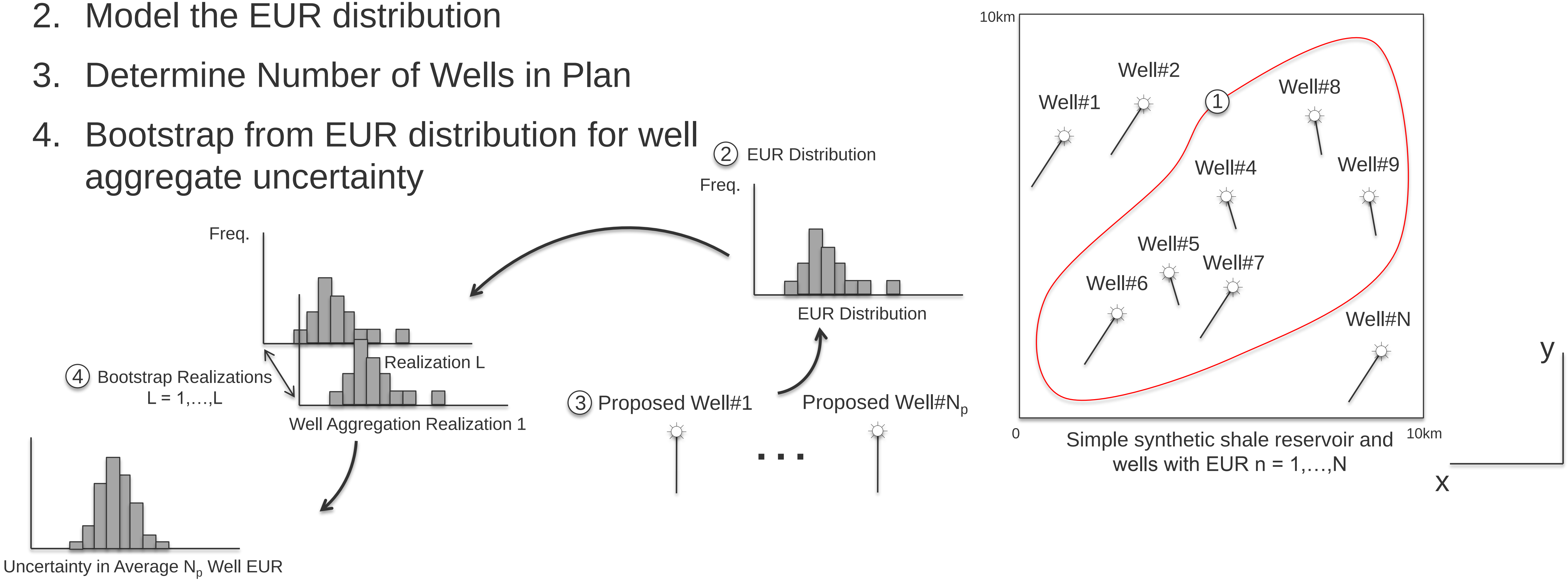
1. Identify analogous wells
2. Model the EUR distribution
3. Determine Number of Wells in Plan



Introduction - Prerequisites

Bootstrap Approach (SPEE, 2010)

1. Identify analogous wells
2. Model the EUR distribution
3. Determine Number of Wells in Plan
4. Bootstrap from EUR distribution for well aggregate uncertainty



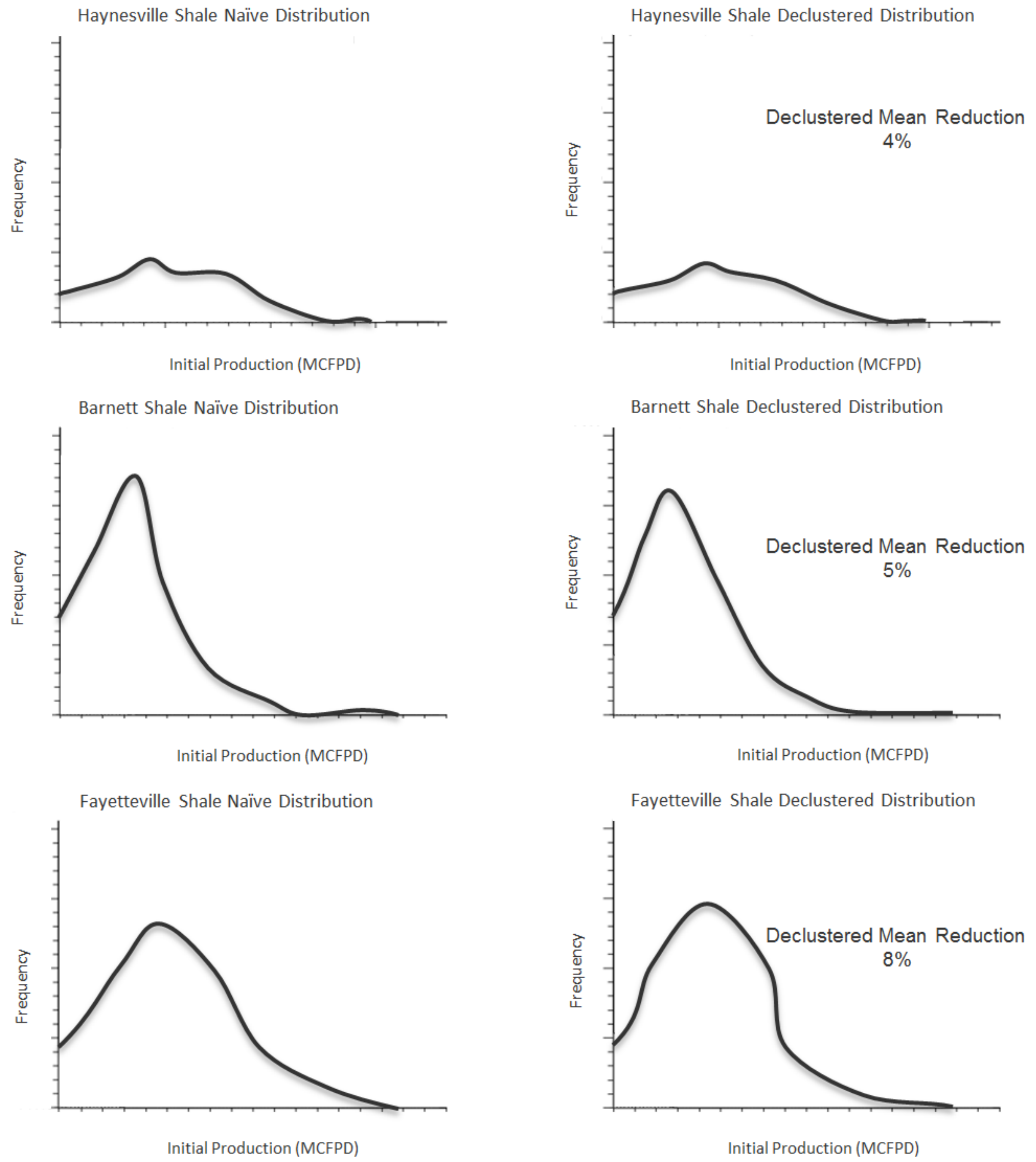
Unconventional Reservoir Uncertainty Assessments

1. Introduction
2. **Maximizing Use of Analogs**
   – Representative Distributions
   – Spatial Continuity
3. Direct Assessment of Block Uncertainty
4. Well Aggregate Uncertainty
5. Conclusions

Maximizing Use of Analogs

Representative Statistics

- Compiled IP datasets for domestic shale plays
  - Filtered datasets to reduce influence of completions
- Representativity an issue even with large datasets and relatively good coverage
  - Observed changes in naïve to declustered means of 4 – 8%

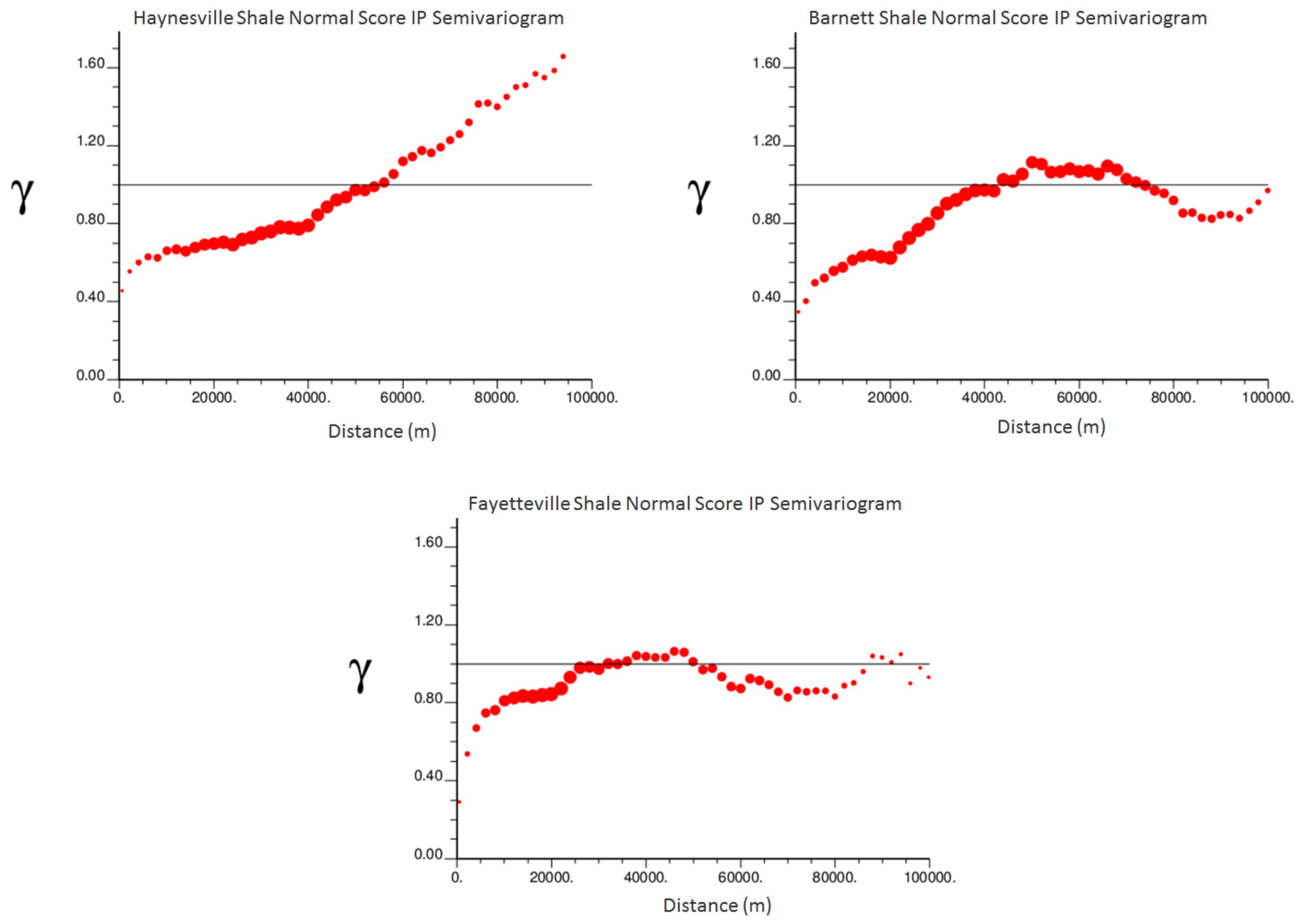


Naïve and declustered distributions from cell-based declustering (Deutsch and Journel, 1998)

Maximizing Use of Analogs

Spatial Continuity

- Experimental isotropic semivariograms are calculated for the normal score transform of well IP



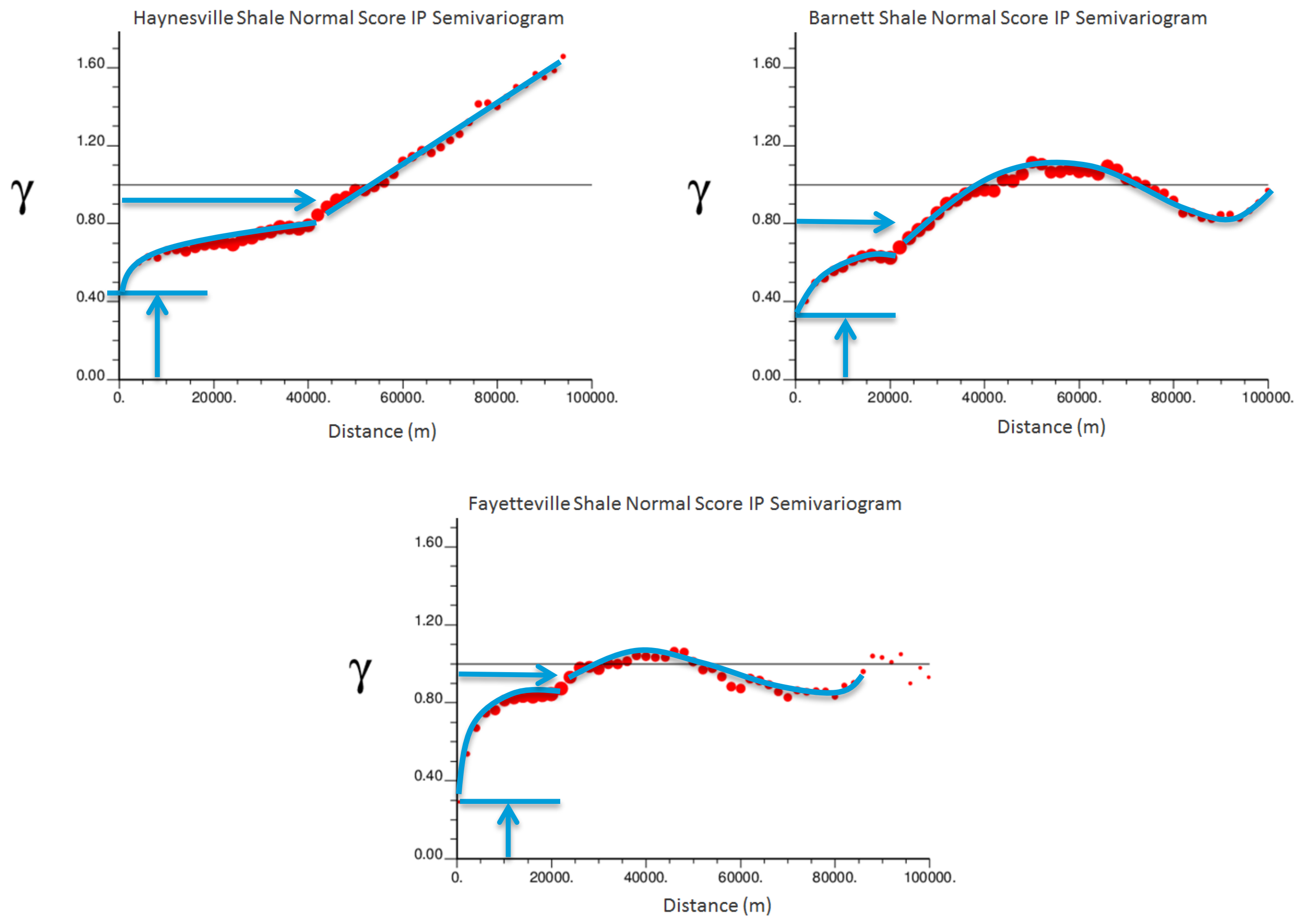
Experimental semivariograms for domestic shale IP (Pyrcz and Deutsch, 2014)

Maximizing Use of Analogs

Spatial Continuity

- Experimental isotropic semivariograms are calculated for the normal score transform of well IP
  - 30-40% relative nugget effect
  - long correlation ranges
  - indication of long range trends.

- These shale plays indicate a high degree of variability between adjacent wells, but also some degree of correlation or in-formation over long distances.



Experimental semivariograms for domestic shale IP (Pyrcz and Deutsch, 2014)

Unconventional Reservoir Uncertainty Assessments

1. Introduction
2. Maximizing Use of Analogs
3. **Direct Assessment of Block Uncertainty**
   - Methodology
   - Results
4. Well Aggregate Uncertainty
5. Conclusions

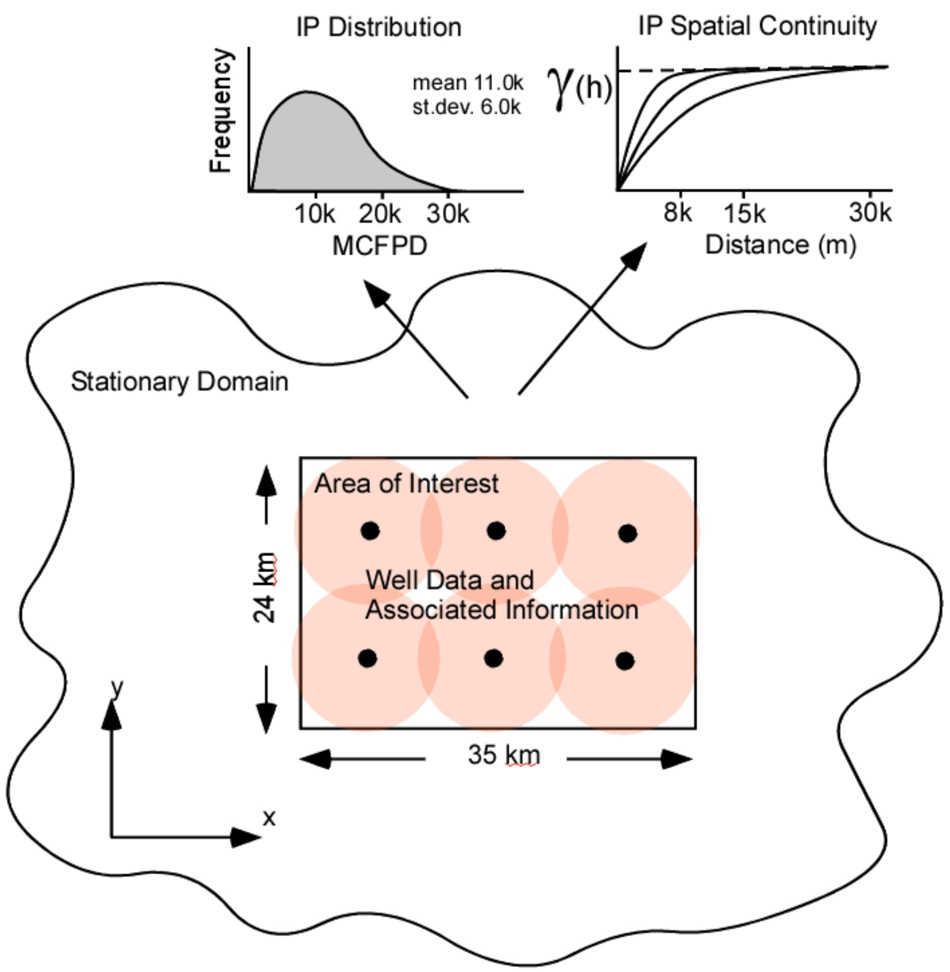
Direct Assessment of Block Uncertainty - Methodology

Model of the Relationship Between Block Uncertainty:

1. Representative EUR / IP Distribution
2. Spatial Continuity
3. Size of Appraised Block
4. Number of Wells

Set up a numerical model to accomplish this

- Assumptions:
  - Known production rate distribution and variable spatial continuity over a stationary domain
  - No black swans



Assumptions for the direct assessment of block uncertainty.

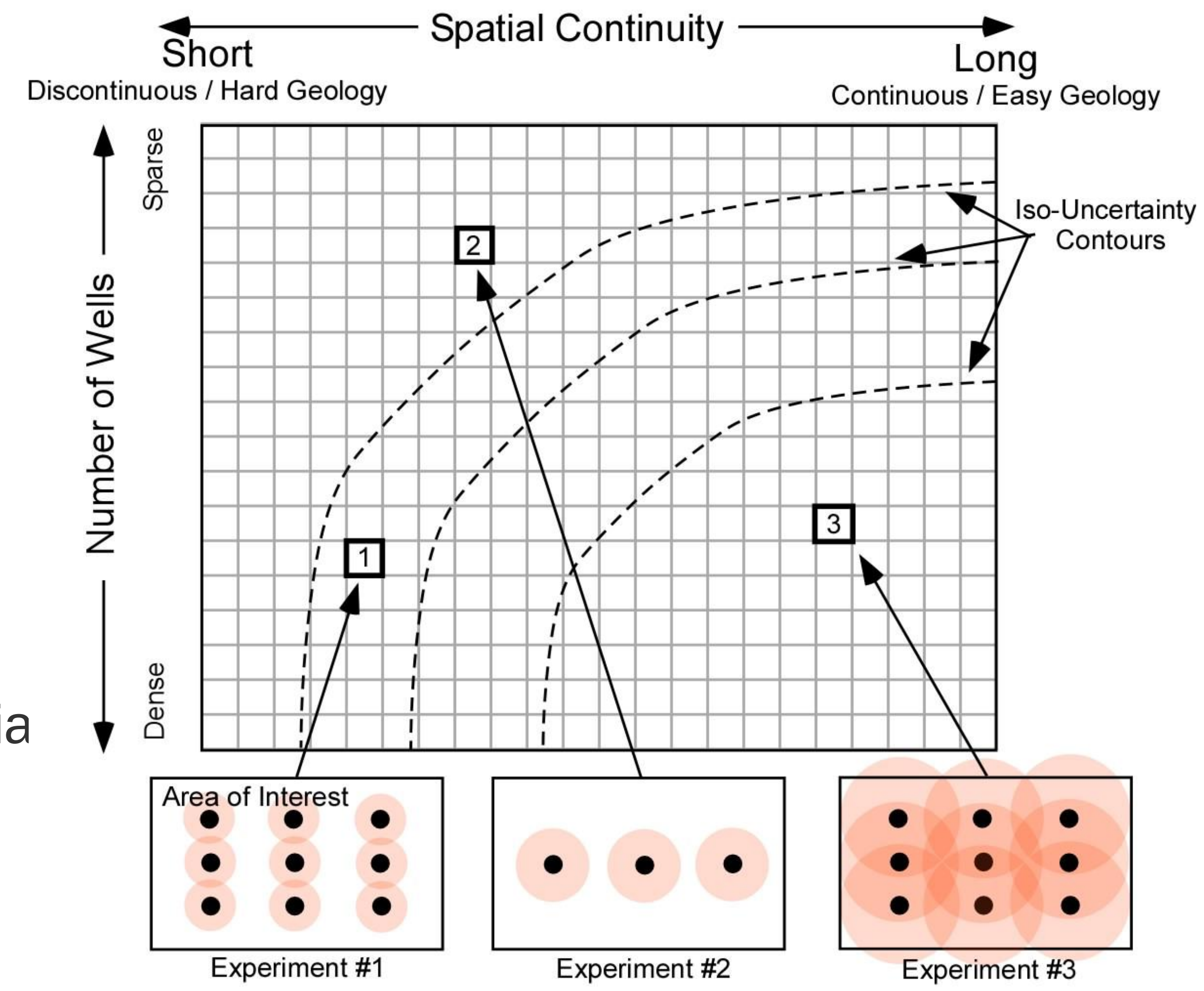
Direct Assessment of Block Uncertainty - Methodology

Model of the Relationship Between Block Uncertainty:

1. Representative EUR / IP Distribution
2. Spatial Continuity
3. Size of Appraised Block
4. Number of Wells

Set up a numerical model to accomplish this

- Assumptions:
  - Known production rate distribution and variable spatial continuity over a stationary domain
  - No black swans
  - Response surface based on equal well spacing



Construction of block uncertainty response surface (Pyrcz and Deutsch, 2012)

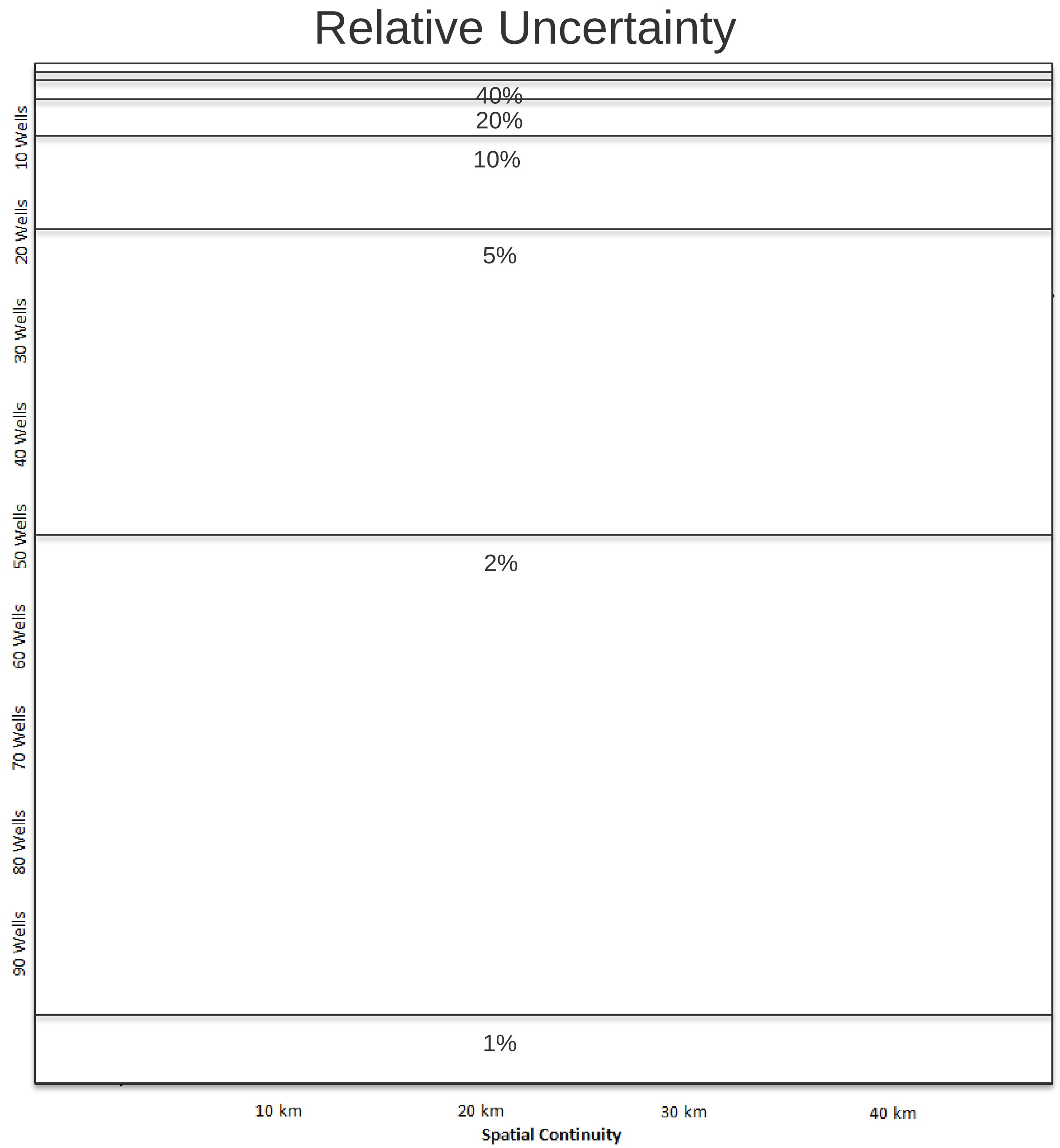
Direct Assessment of Block Uncertainty - Methodology

What does the Bootstrap uncertainty model look like?

- Comments
  - Only sensitive to number of wells given constant production distribution
  - No spatial context

- The uncertainty assessment is insensitive to:
  - Geological complexity
  - Data coverage

- This approach is not sufficient to assess shale play uncertainty.



Direct Assessment of Block Uncertainty - Results

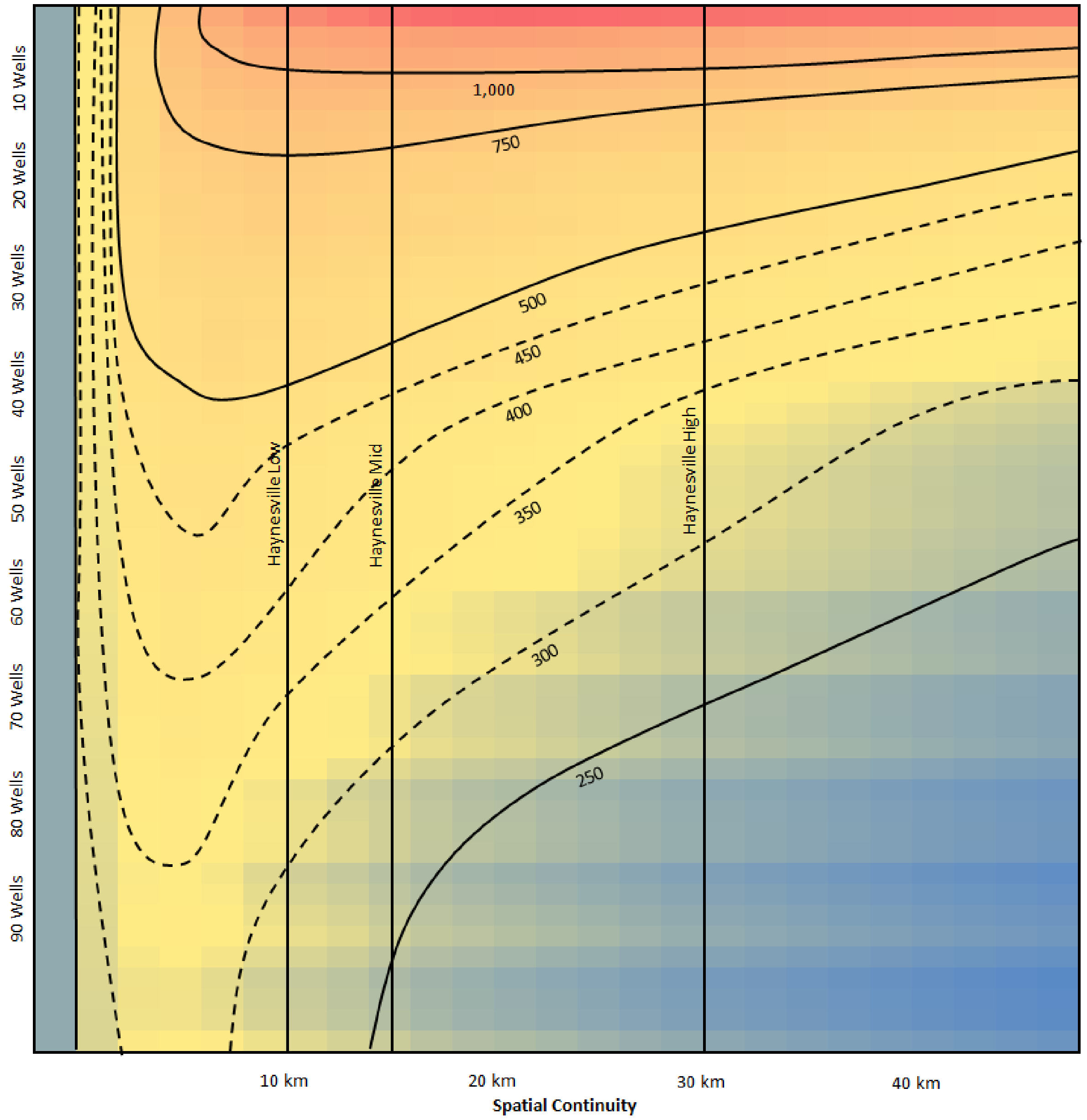
Global Kriging Approach

- Estimate block uncertainty

Interpretation of Response Surface

- Opportunity to visualize uncertainty
  - Trade-offs and relative importance of factors
- Results are complicated by interactions of:
  - Impact of spatial continuity on maximum uncertainty
  - Strong stationarity decision

Absolute Uncertainty

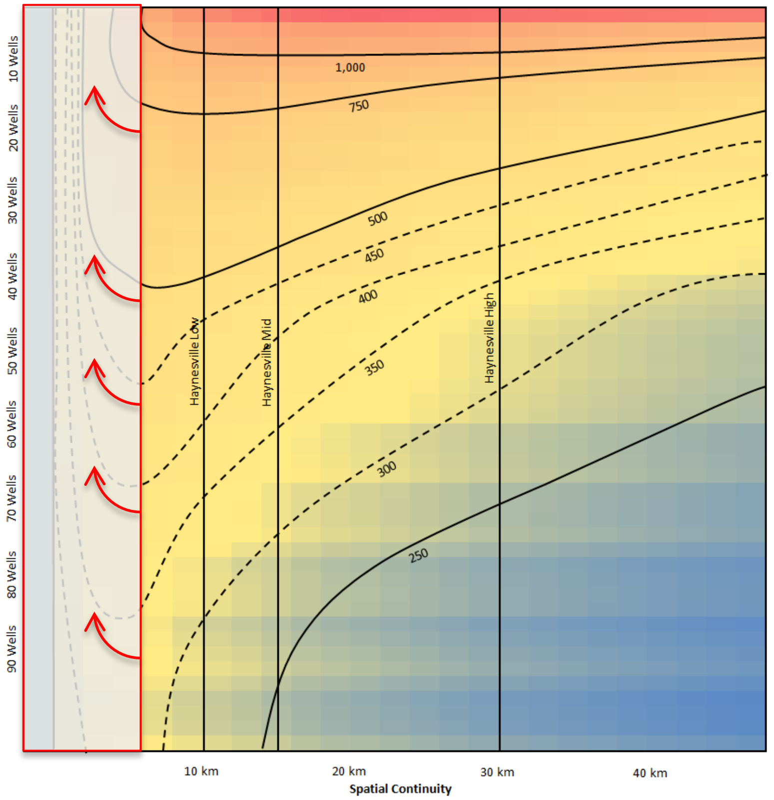


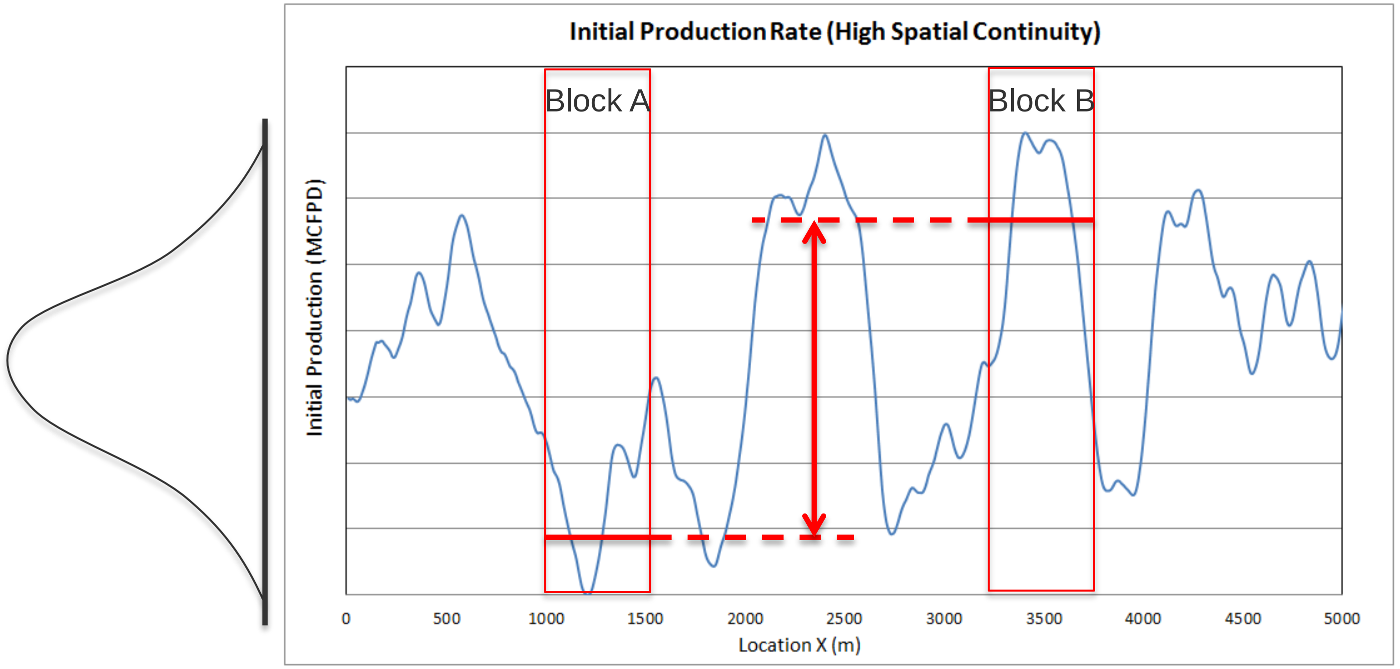
Block uncertainty vs. number of wells and spatial continuity (Pyrcz et al., 2016).

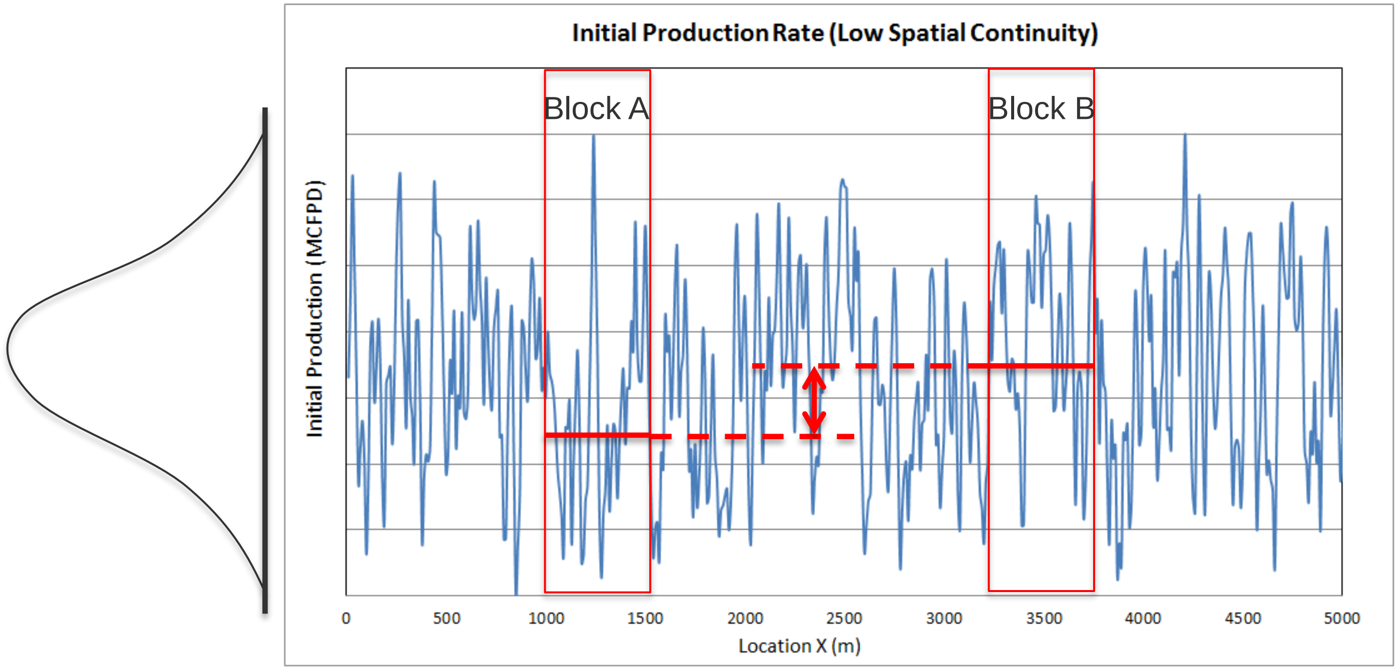
Direct Assessment of Block Uncertainty - Results

Interpretation of Response Surface

- Impact of short variogram range?
  - Under stationarity of global distribution possible variation of a block is quite limited.
  - Could account for uncertainty in the global distribution.



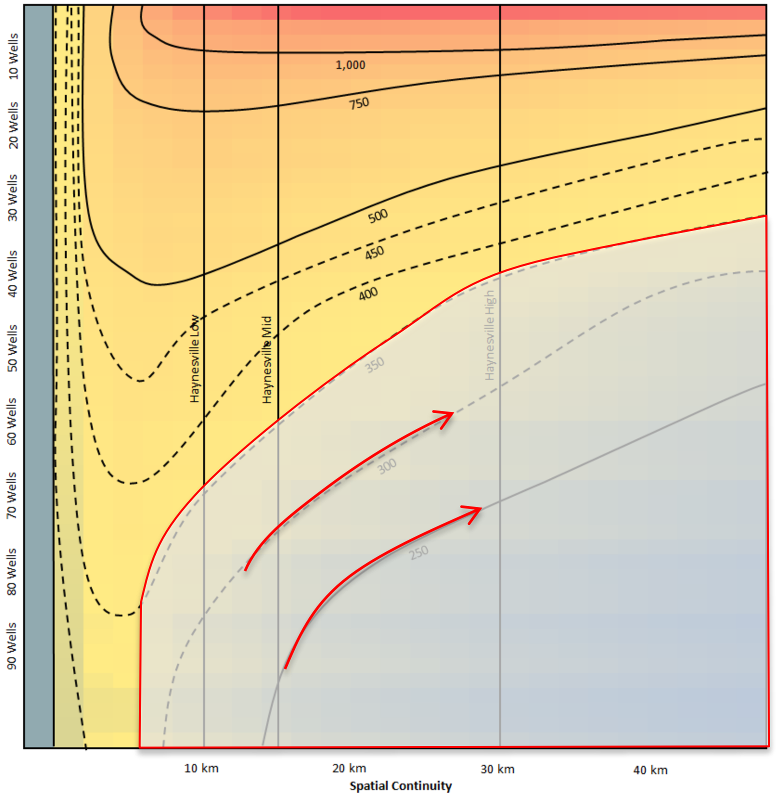




Direct Assessment of Block Uncertainty - Results

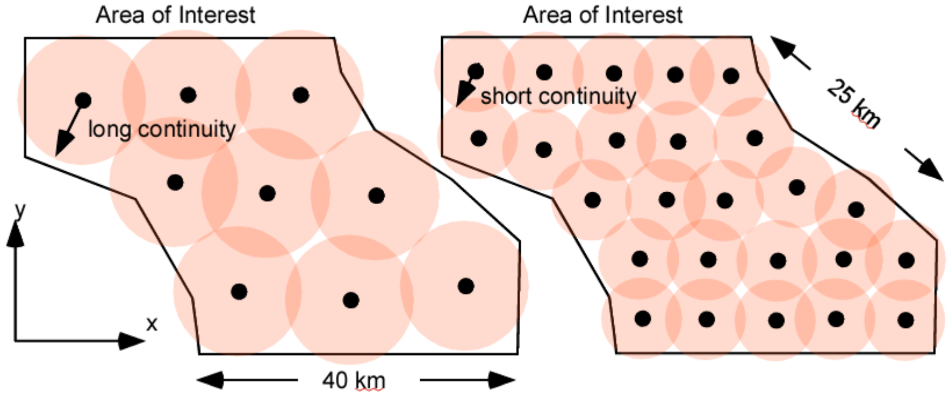
Interpretation of Response Surface

- Well Density and Spatial Continuity Trade-off?
  - Equivalent coverage with few wells and long spatial continuity and many wells and short spatial continuity



Few Wells
Long Range Spatial Continuity

Many Wells
Short Range Spatial Continuity



Same coverage and resulting block uncertainty.

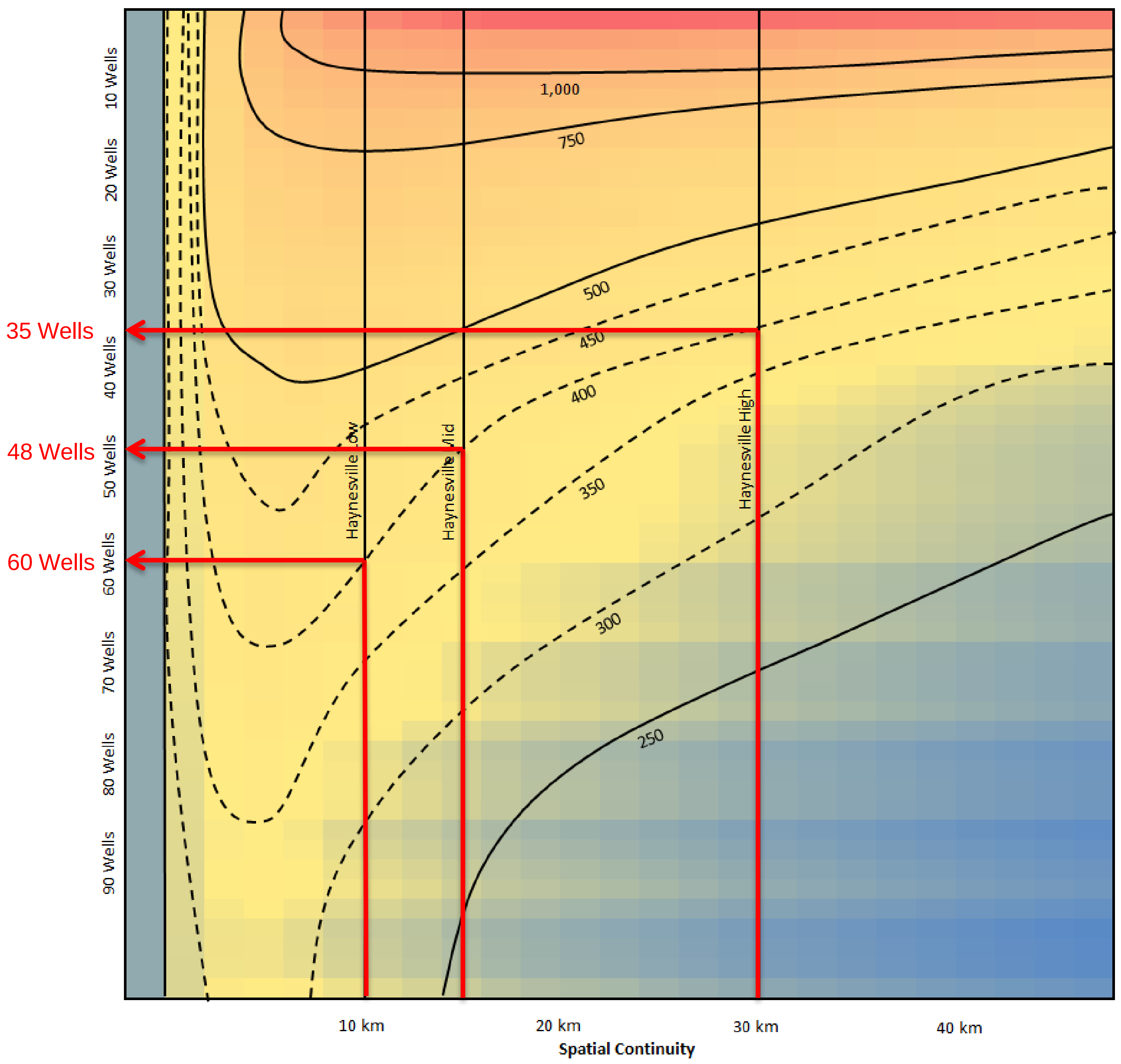
Direct Assessment of Block Uncertainty - Results

Field Application

- Selection of required appraisal well count
    1. Construct response surface for specific analog-based production distribution and spatial continuity and block size.
    2. Assign acceptable level of uncertainty
    3. Assign range of spatial continuities (low – mid – high).
    4. Look up required well count.

- Given Haynesville analog and 20 x 20 mile block:
    - To achieve a block accuracy production rate less than +/- 400 MCFPD requires 35 – 48 – 60 equally spaced wells in the block.

Absolute Uncertainty



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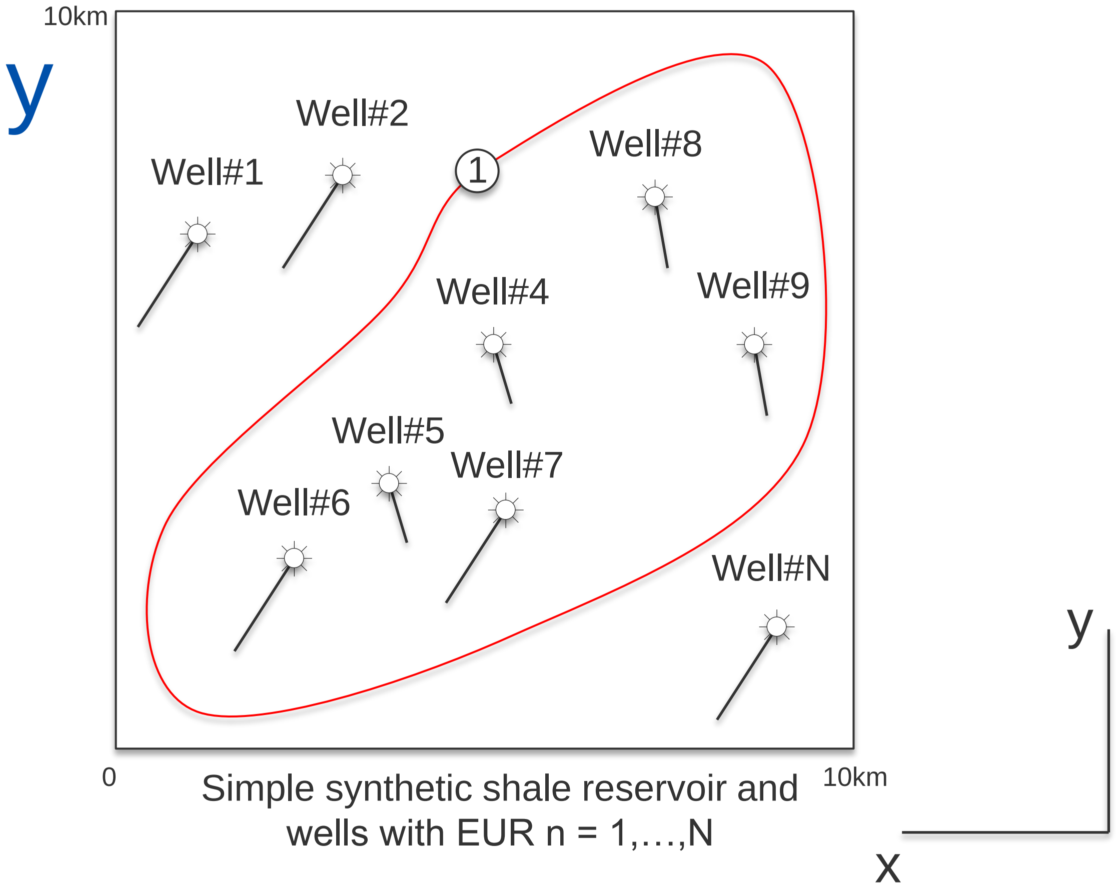
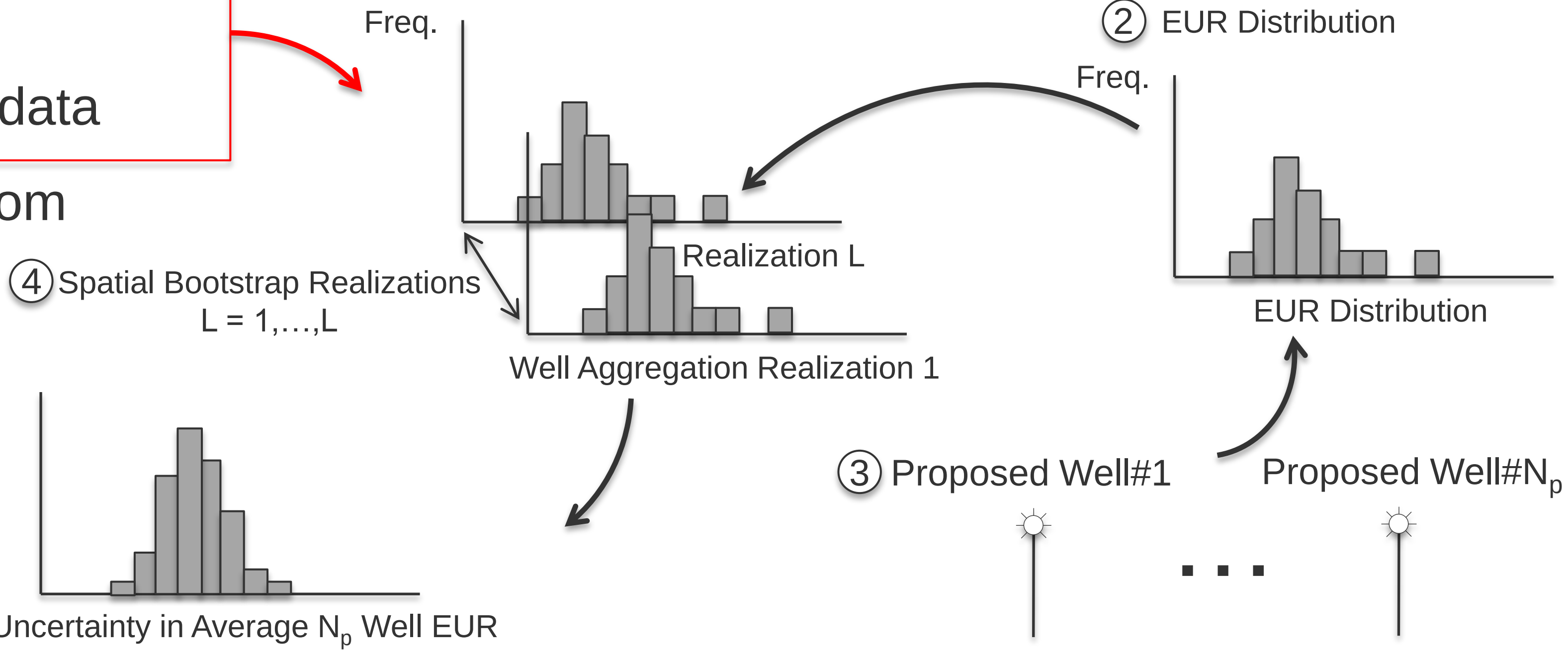
Well Aggregate Uncertainty - Methodology

New Method for Well Aggregation

- Expansion of SPEE#3 Monograph Method
  - Spatial bootstrap is a variant of bootstrap that accounts for spatial correlations when resampling (Journel, 1994)
  - New method accounts for:
    - Proposed and previous well locations
    - Spatial Continuity
    - Local trends and secondary data
  - Based on sequential simulation from EUR distribution



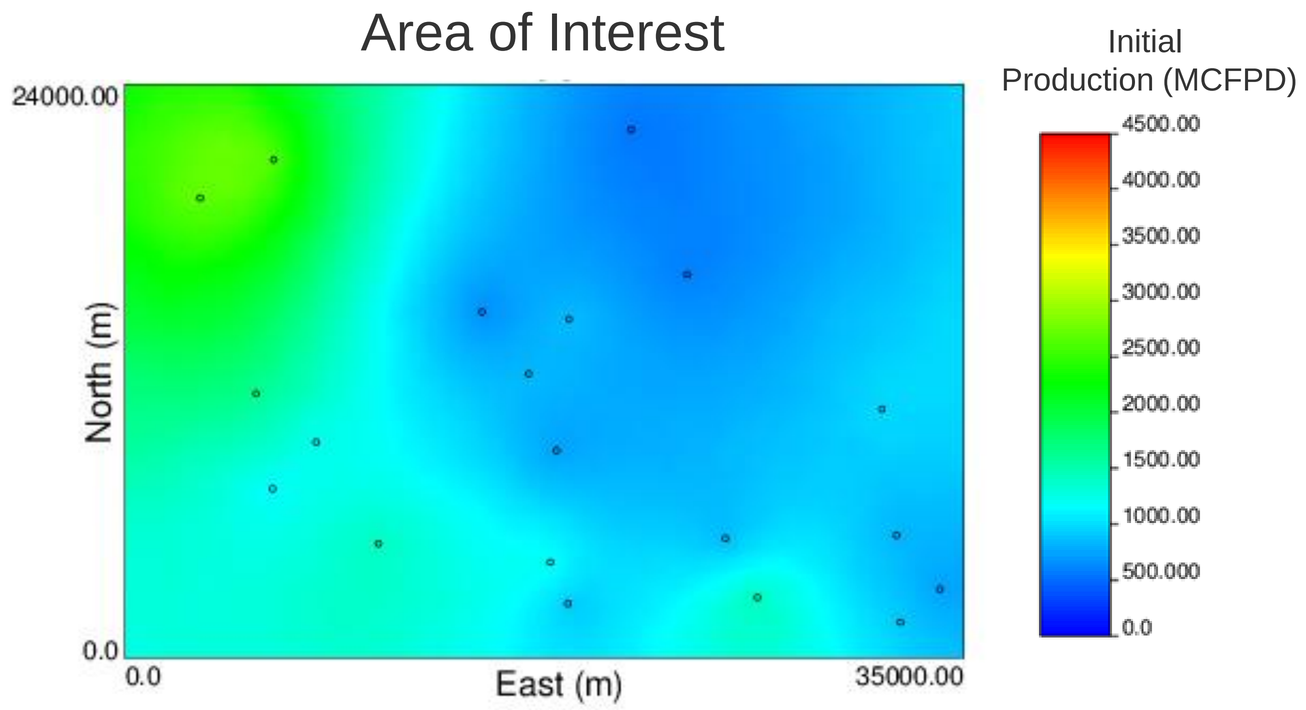
Simple synthetic shale reservoir and wells with EUR n = 1,…,N



Well Aggregate Uncertainty - Methodology

Well Aggregation Example

- Simple unconventional block with:
  - Defined area of interest
  - Within block trends ➡
  - Previously drilled wells ➡
  - Global IP distribution
  - IP spatial continuity model

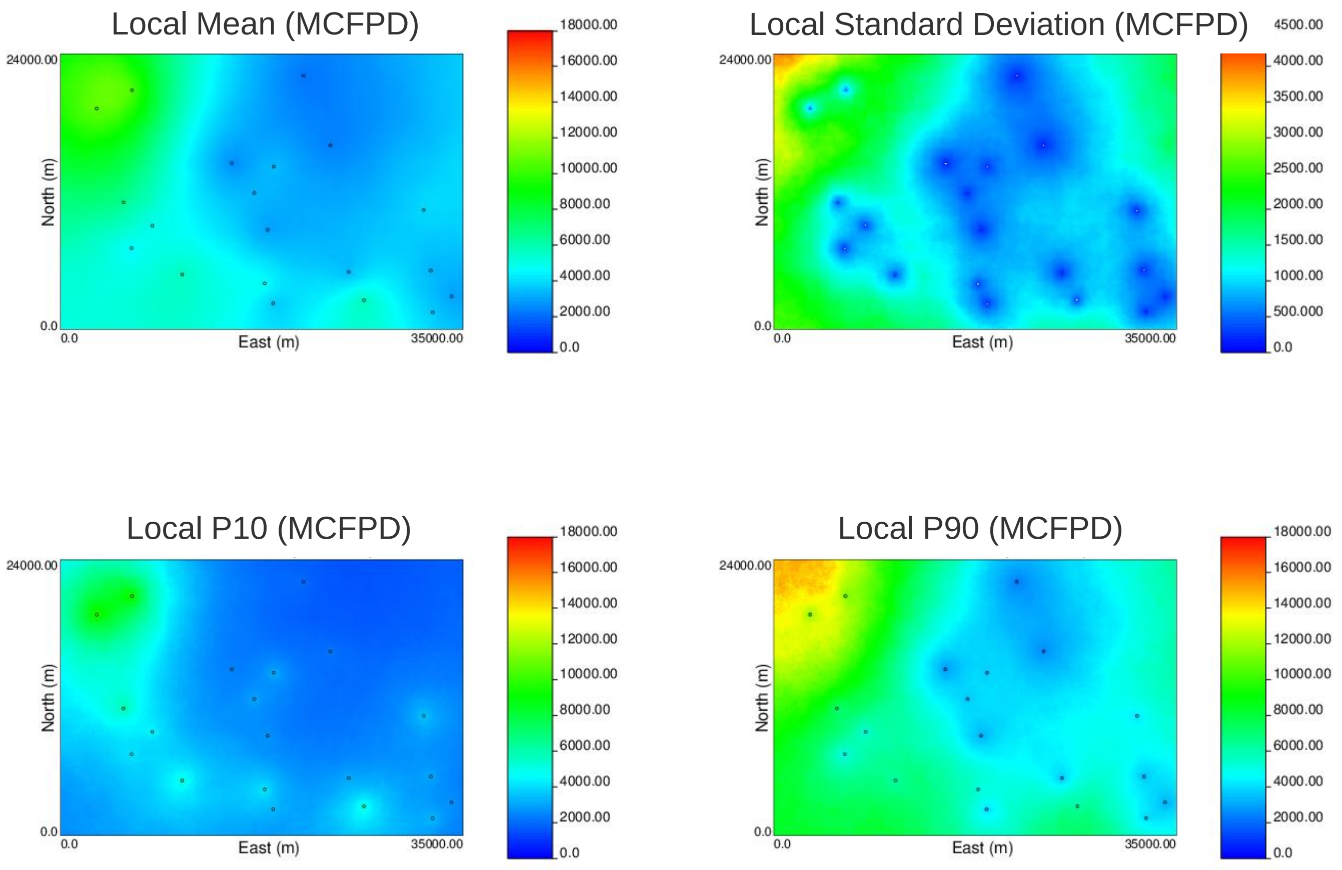


Available wells and IP trend

Well Aggregate Uncertainty - Methodology

Well Aggregation Example

- Simple unconventional block with:
  - Defined area of interest
  - Within block trends
  - Previously drilled wells
  - Global IP distribution
  - IP spatial continuity model
  - Local uncertainty ➡
- Additional uncertainty:
  - Any input could be considered uncertain and the associated uncertainty carried through the workflow



Local Distributions of Uncertainty (after Olea et al., 2011)

Well Aggregate Uncertainty - Methodology

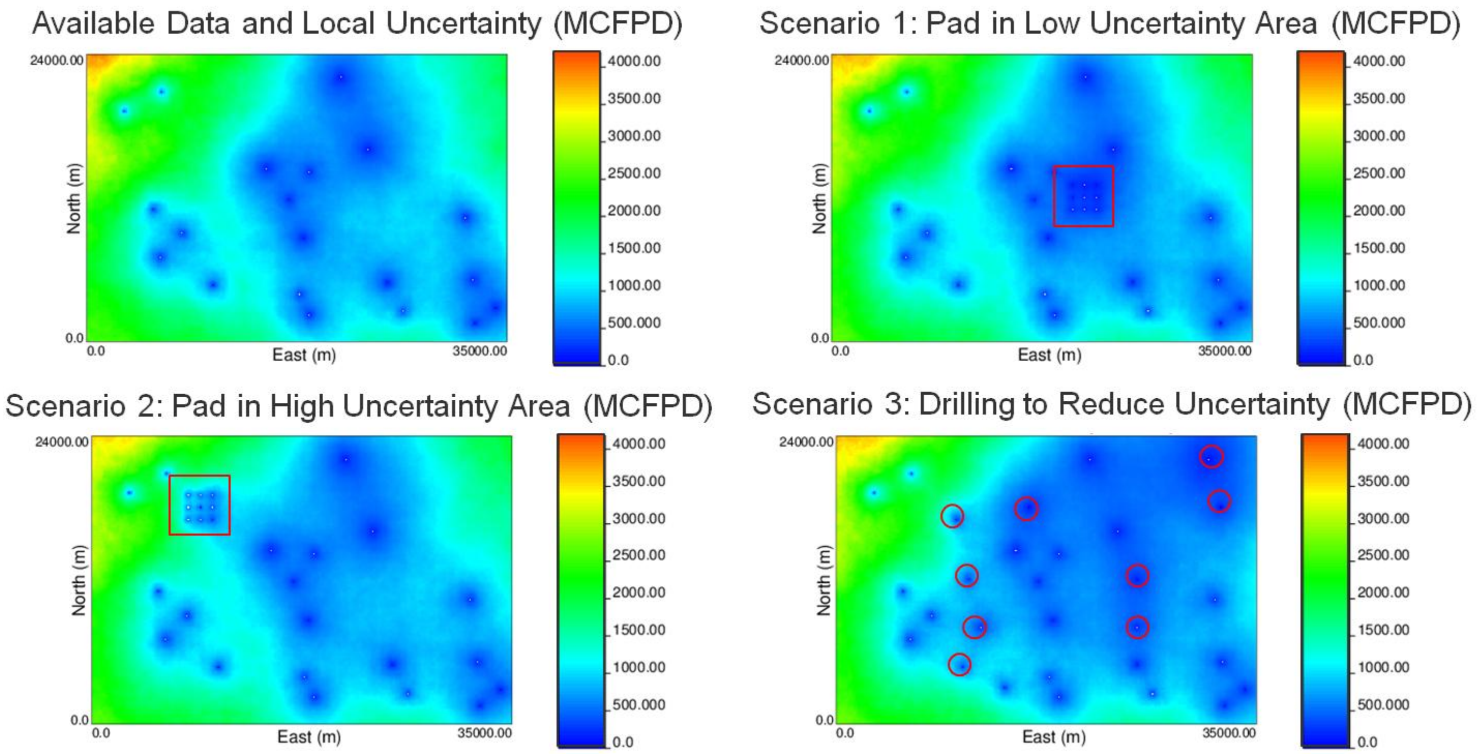
Well Aggregation Example

- What is the uncertainty in the aggregate result of a well plan?
- Three proposed well scenarios

  Scenario #1: Pad in Low Uncertainty Are

  Scenario #2: Pad in High Uncertainty Area

  Scenario #3: Drilling to Reduce Uncertainty

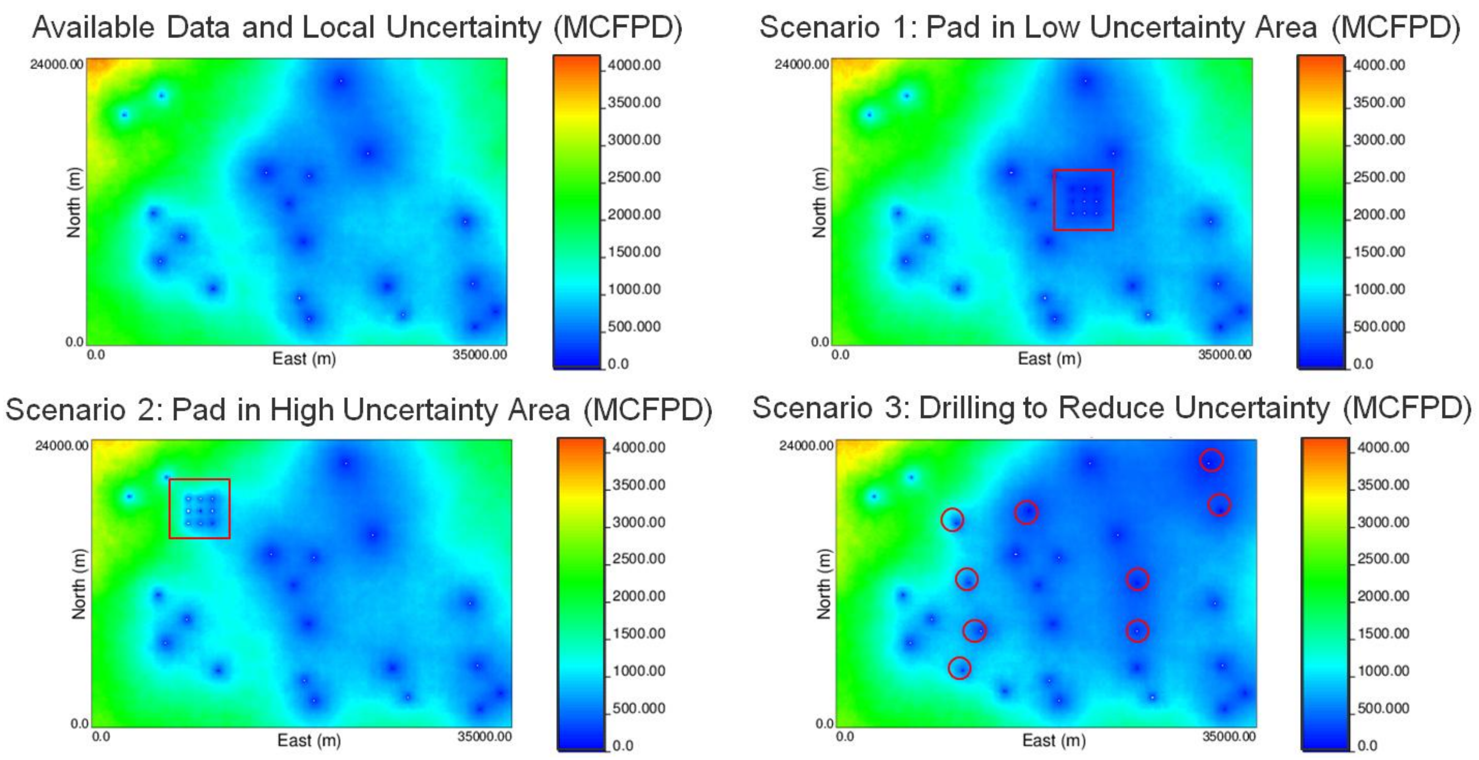


Previously drilled wells and 3 proposed well scenarios

Well Aggregate Uncertainty - Methodology

Well Aggregation Example

- Trade-offs:
  - Local uncertainty
    - More or less local information
    - Change in local variability
  - Data redundancy
    - High correlation between wells results in higher aggregate uncertainty
    - Low correlation between wells results in lower aggregate uncertainty (averaging out high and low results).



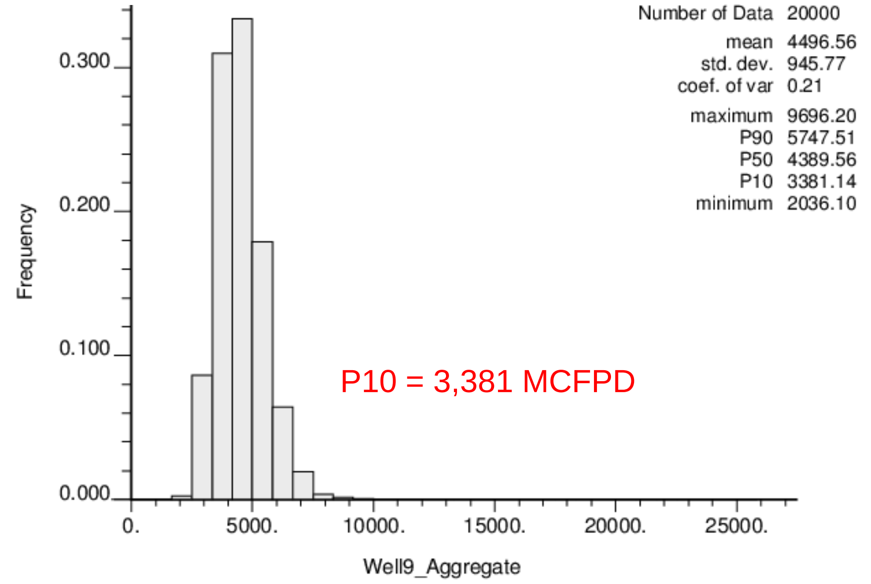
Previously drilled wells and 3 proposed well scenarios

Well Aggregate Uncertainty - Results

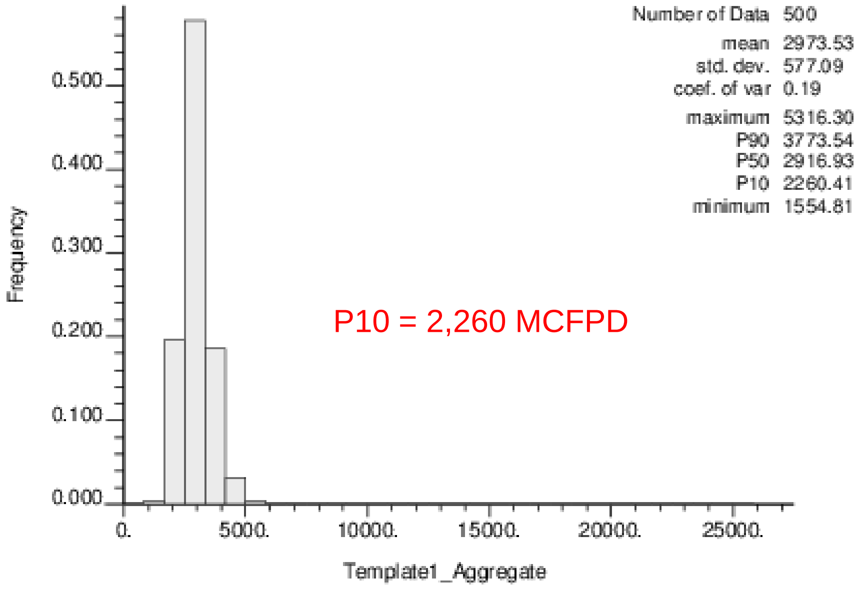
Well Aggregation Results

- 3 Well Plans Benchmarked with SPEE#3 Result:
  - Significant difference in well aggregate results
    - Expected result
    - Low case (see P10 result)

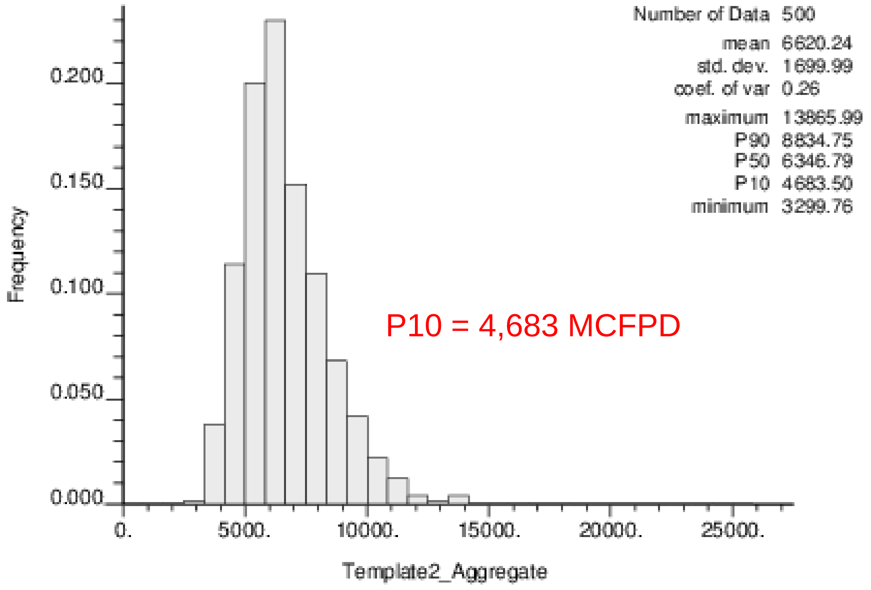
SPEE#3 Method / Bootstrap (MCFPD)



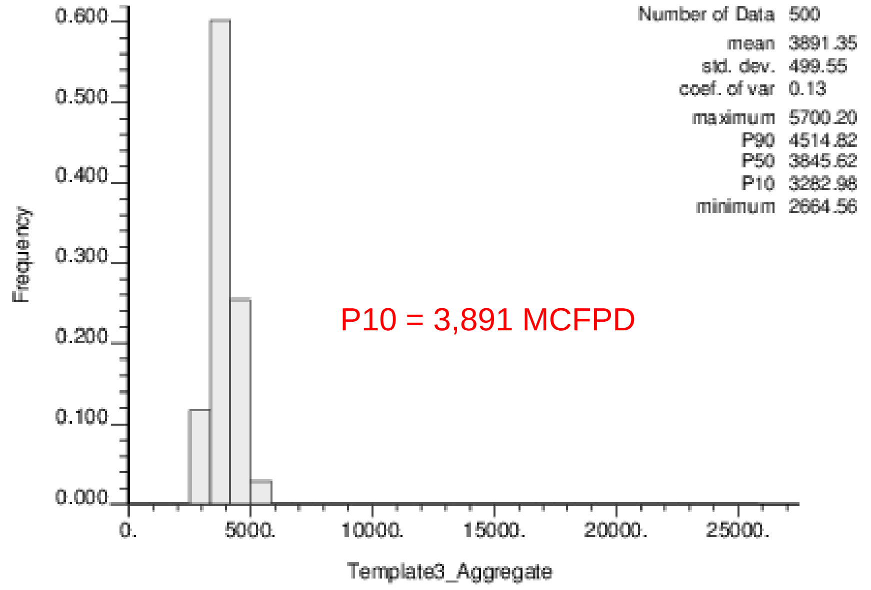
Scenario 1: Pad in Low Uncertainty Area (MCFPD)



Scenario 2: Pad in High Uncertainty Area (MCFPD)



Scenario 3: Drilling to Reduce Uncertainty (MCFPD)



Unconventional Reservoir Uncertainty Assessments

Conclusions

Contributions to Unconventional Uncertainty Modeling:

- Representative Domestic Shale Production Statistics
  - Impact of well clustering
  - Common spatial continuity structures and interpretations
- Direct Assessment of Block Uncertainty
  - Application of global kriging to model general block uncertainty to support well count decision
- Well Aggregate Uncertainty
  - Expansion of SPEE#3 monograph methodology with spatial concepts

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