Reservoir management in the age of big data

Since the 1980s, Norwegian companies have been pioneers in advanced oil and gas technologies, helping the industry boost recoverable volumes in fields worldwide.

Resoptima is continuing that Norwegian legacy through its suite of software tools. ResX delivers ensemble-based reservoir modelling and history matching to the oil and gas industry that will increase productivity and ultimate hydrocarbon recovery.
Reservoir modelling – current challenges

Every year, E&P companies invest millions of dollars in an effort to improve their understanding of the future behaviour of their fields.

Traditional reservoir modelling approaches are often costly and time consuming, requiring months or even years for asset teams to integrate new data from recently drilled wells, seismic surveys, or production.

Lack of efficient software tools and work processes that are not necessarily designed for an age where

- **Models are often tailor-fitted** to outdated data, compromising on applicability by introducing artificial wells or box multipliers on the petrophysical properties in the dynamic data conditioning (history matching) phase.

- **Static and dynamic data conditioning are often treated as disconnected processes**, often with limited communication between the different subsurface disciplines, leading to model inconsistencies.

- A key milestone of a reservoir modelling project is often to generate one single “base-case” model. As a consequence, a lot of time and effort is spent discussing modelling approaches and/or data interpretations that in the end are not important for business-critical decisions.

- Uncertainty quantification is often an ad-hoc exercise, where the inherent uncertainties in the data interpretation and modelling process are not captured and propagated.

Consequently, a large number of reservoir modelling projects fail to meet their initial project deadlines, and produce models that deliver results with a false sense of security. More problematic, however, is that reservoir models become notoriously difficult to update when new data arrives.

For these reasons, it is not unexpected that the reliability of the resulting models can be questioned, where we often see extreme differences between reported reserves and the actual production.

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1 (Thomas, 1998)
Reservoir modelling is—in mathematical terms—known as an inverse problem. We use the dynamic information collected from the field to reverse-engineer a mathematical description of the reservoir model and gain confidence in predicting the future behavior of the field.

A 3-D reservoir model is parameterized using

- 2-D surfaces describing the structure of the grid model;
- Spatially dependent variables (3-D arrays) describing reservoir properties, such as: permeability, porosity, initial water saturation, etc.; and
- Scalar variables, such as: oil-water contacts in different segments of the reservoir, functions describing the shape of relative permeability curves, etc.

This means that for realistic problems, millions of unknown model parameters have to be estimated using measured static and dynamic data.

Since the 1980s, a large number of software tools have been developed that primarily address the challenge of constructing and simulating 3-D reservoir models.

Geostatistical methods\(^2\) are the foundation of these software tools, making it technically possible to implement repeatable reservoir modelling workflows that incorporate static data, while accounting for uncertainty in the process. That being said, as the current best practices in reservoir modelling are designed with a primary objective of building a single deterministic model, the efficiency of repeatable reservoir modelling workflows is not fully utilized by the oil and gas industry today.

Dynamic data conditioning, on the other hand, has for many years been the crux of reservoir modelling projects. Standard approaches will—for practical purposes—require a re-parameterization (simplification) of the existing model parameters as part of the dynamic data conditioning process.

These re-parameterization techniques are often introduced as region based multipliers on petrophysical properties in selected areas of the reservoir, rather than directly addressing the model parameters as they are defined in the static data conditioning process.

Unfortunately, these model re-parameterizations—primarily motivated by a requirement to simplify the dynamic data conditioning process—often lead to large and unphysical modifications to a handful of scalar variables, which introduce inconsistencies in the output models and make it hard to update models when new data arrive.

With recent technological advances, the amount of data we collect from a reservoir is rapidly increasing, making the standard approaches to reservoir modelling obsolete in the age of big data. For this reason, we have in recent years seen an increased effort by the oil and gas industry to develop solutions that attempt to overcome the challenges imposed by the traditional reservoir modelling approach and take advantage of the recent boost in computational power\(^3\).

\(^2\) (Journel & Huijbregts, 1981), (Chiles & Delfiner, 1999)
\(^3\) (Zachariassen, et al., 2011), (Pettan & Strømsvik, 2013), (Skjervheim, Hanea, & Evensen, 2015), (Yeh, et al., 2016)
Reservoir modelling using ResX

Through ResX, Resoptima capitalizes on over 20 years of research efforts to provide an efficient solution to the challenges highlighted in the previous section.

With ResX, dynamic data conditioning is a natural extension of the static data conditioning process. Key elements include

- reservoir model generation using repeatable workflows,
- automated and consistent integration of static and dynamic data in an efficient manner, and
- reservoir modelling and data conditioning in a probabilistic (ensemble-based) framework.

Subsurface teams using ResX capture the full potential of available data—when they arrive—to make improved reservoir management decisions.

ResX is founded on the ensemble Kalman based technique (first introduced by Geir Evensen in 1994\(^4\)), more specifically the Kalman Smoother. Despite the apparent simplicity of the method, it is extremely powerful when solving complex inverse problems in high dimensions. For this reason, it is used in many areas including weather forecasting, hydrology, oceanography and finance\(^5\).

Note, however, that there are key differences between the textbook implementation of the ensemble Kalman update scheme\(^6\) and ResX\(^7\). By innovative solutions, ResX overcomes the challenge of underestimating the posterior covariance in subsurface application, enabling highly scalable ensemble-based reservoir modelling and history matching – not limited by the type or number of uncertainty parameters. As a result, ResX is continuously and successfully applied on a large variety of fields worldwide; from green fields in the North Sea\(^8\), to stratigraphic giants in the Middle East\(^9\).

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4 (Evensen, 1994)
5 See e.g. (Echevin, De May, & Evensen, 2000), (Mitchell, Houtekamer, & Pellerin, 2002), (Bertino, Evensen, & Wackernagel, 2002), (Allen, Eksnes, & Evensen, 2003), (Keppenne & Rienecker, 2003), (Snyder & Zhang, 2003), (Moradkhani, Sorooshian, Gupta, & Houser, 2005), (Bianco, Cominelli, Dovera, Naevdal, & Valles, 2007), (Zachariaassen E. et al., 2011), (Pettan & Stramsvik, 2013), (Chen & Oliver, 2014), (Barilansyah, Skare, Munck, & Sætrom, 2015), (Chen, 2015), (Emerick, 2016), (Hanea, Ek, Massart, & Pettan, 2016)
6 see e.g. (Evensen, 2003)
7 (Sætrom, Morell, & Munck, 2015)
8 (Sætrom, Selseng, MacDonald, Kjøseth, & Kolbjørnsen, 2016)
9 (Maucec, De Metos Ravanelli, & Lyngra, 2016).
Rather than anchoring to one single base-case model, ResX uses repeatable workflows to generate multiple reservoir models that are all equally plausible and consistently honor all available data. Hence, the reservoir modelling and data conditioning efforts are carried out in one single step making multidisciplinary collaboration a natural part of the process, avoiding introduction of model inconsistencies.

The starting point for ResX is an ensemble of reservoir models that captures the distribution of the unknown 3D grid properties, 2D surfaces and scalar variables used to parameterize a 3D reservoir model.

In the dynamic data conditioning phase, ResX combines efficient algorithms, such as the adaptive plurigaussian facies modelling technique, with the know-how of the subsurface team to update the full ensemble of reservoir models. Because every model is equally probable (given the current static data measurements), none of the models are thrown away during history matching. Instead, ResX directly updates the parameters used in the model building process—honoring data, while minimizing the changes made to the input models. This ensures that the model uncertainty is not reduced unless the data measurements strongly support it, reducing the risk of overfitting models to the current data.

Key to ensuring physical and realistic updates in the history matching phase is to use your reservoir knowledge as part of the conditioning process. Take the example of a sealing fault closing off the communication between two segments of the reservoir. You have a priori knowledge that data from wells in one segment will not affect properties in the other, and vice versa, hence you need to include this information as part of the conditioning process. With ResX, the user can easily control the area of influence of the dynamic data using streamlined user interfaces.

ResX can also be applied in the early field development phase. In this phase, data is limited, which makes it even more important to integrate it in the best possible way. Valuable information can be found in Drill Stem Tests (DSTs) regarding reservoir characteristics including reservoir thickness, distance from wells to flow barriers, permeability, support from aquifers, etc.

With the ResX DST functionality, this valuable information can be transferred to the ensemble of models. By conditioning models to buildup pressures and taking into account uncertainties in both data interpretation and the modelling workflow, ResX can provide crucial information in the early field development phase, which is hard to capture using traditional approaches.

By capturing and propagating uncertainty in all parts of the modeling process, ResX brings improved reservoir understanding. The information found in the conditioned ensemble can easily be used to evaluate most probable infill locations, capture the uncertainty of when water will break through and estimate the range of expected ultimate recovery; in other words, assist asset teams to manage decision-making risks more efficiently.
The benefits

With ResX, the asset teams significantly reduce the time it takes to consistently update models when new static or dynamic data arrive.

While model updating can take months or years using a traditional reservoir modelling approach, the asset team can achieve the same task in hours or days using ResX.

The key components to the success of ResX are:

- **Scalability and robustness** makes ResX equally applicable for small and large reservoirs. Regardless of the reservoir size (few wells with limited production history or hundreds of wells with decades of production history), ResX can obtain 50-100 models that are consistently honoring the measured static and dynamic data on the field scale and on a well-by-well basis, using 200-400 simulations in total.

- **Repeatable reservoir modelling workflows**, where the asset team can immediately get feedback on the selected modelling strategy and potentially make adjustments to correct for fundamental problems seen in the simulated data. Using multiple models in the quality assurance process greatly reduces the likelihood of cognitive bias effects that easily occur in traditional reservoir modelling projects, where the primary objective is to create one single base-case reservoir model.

- **Uncertainty quantification**, where the output of a ResX study is an ensemble of reservoir models that are equally probable given the current static and dynamic data. More importantly, ResX captures and propagates the uncertainty in all parts of the modelling process. Neglecting uncertainties is known as one of the greatest causes for failure in model predictions.

- **Team effort**, where knowledge transfer and collaboration between the different subsurface disciplines is a natural part of a reservoir modelling project running ResX.

- **Consistent integration of static and dynamic data** in a probabilistic framework, where the knowledge of the subsurface team is a key part of the process.

With ResX, the subsurface team is able to meet their deadlines and keep their promises by leveraging the latest parallel computing advancements, state-of-the-art research in data integration and the team’s know-how, to produce history matched models that: respect the most up-to-date static and dynamic data measurements, and abide by the reservoir physics.
References


