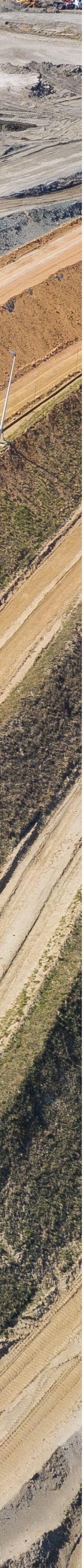
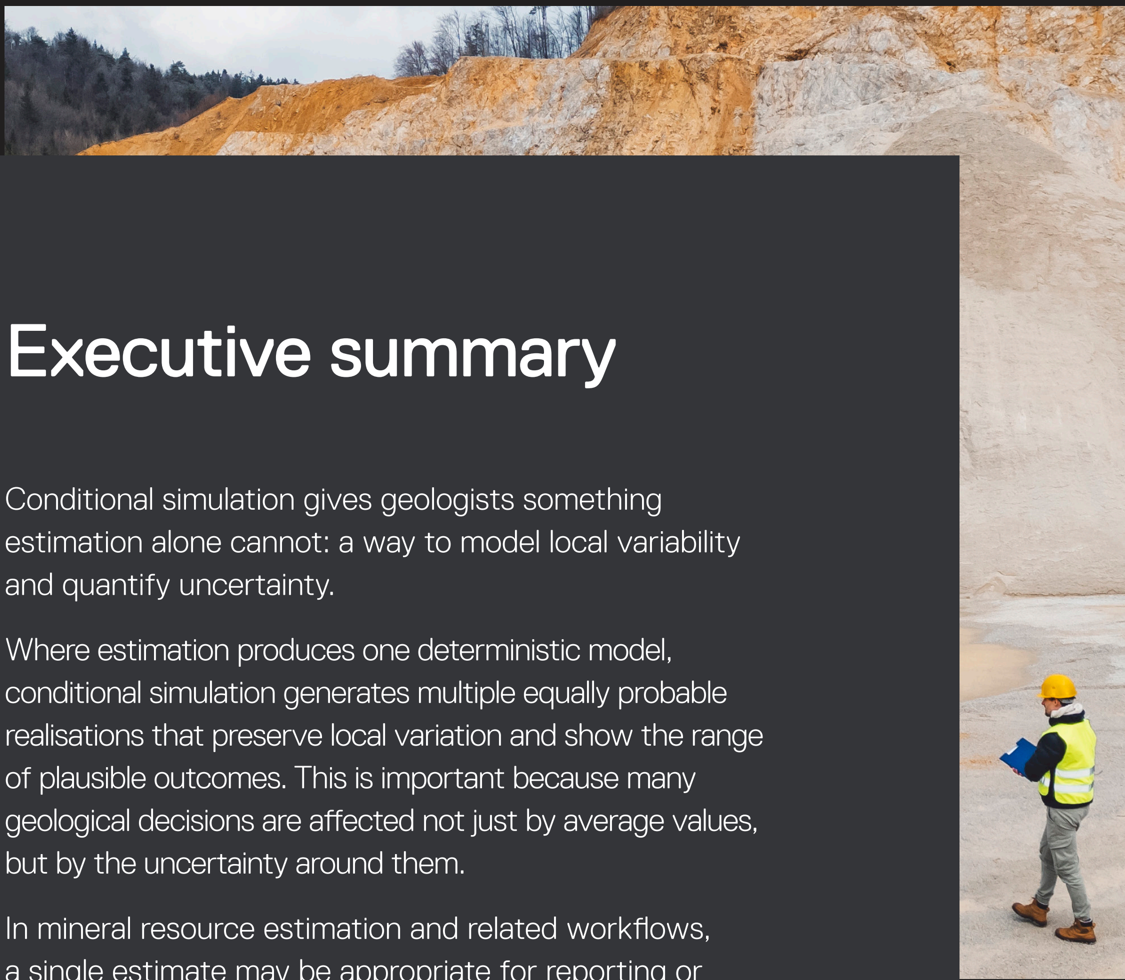
WHITE PAPER

CONDITIONAL SIMULATION IN LEAPFROG AND EVO

Understanding uncertainty and supporting better decisions in mineral resource estimation

Seequent, The Bentley Subsurface Company





Executive summary

Conditional simulation gives geologists something estimation alone cannot: a way to model local variability and quantify uncertainty.

Where estimation produces one deterministic model, conditional simulation generates multiple equally probable realisations that preserve local variation and show the range of plausible outcomes. This is important because many geological decisions are affected not just by average values, but by the uncertainty around them.

In mineral resource estimation and related workflows, a single estimate may be appropriate for reporting or planning, but it can also smooth away the variability that drives risk. Conditional simulation helps make that uncertainty visible and usable.

Seequent's conditional simulation workflow in Leapfrog and Evo is designed to make this process more practical within an integrated resource estimation environment. Leapfrog Geo provides the geological modelling environment, Leapfrog Edge provides the mineral resource estimation workflow, and Evo provides the cloud compute needed to run simulations efficiently. Validation and practical outputs are built into the workflow to support interpretation and use.

This paper explains the role of conditional simulation in geological decision-making, shows where it fits best, and outlines what Seequent provides today in Leapfrog and Evo.

The role of estimation and conditional simulation in geostatistics

Geostatistics provides a framework for predicting the spatial behaviour of geological properties from limited, irregularly spaced data. Within that framework, estimation and conditional simulation are two core approaches that serve different purposes.

Estimation produces a single deterministic model

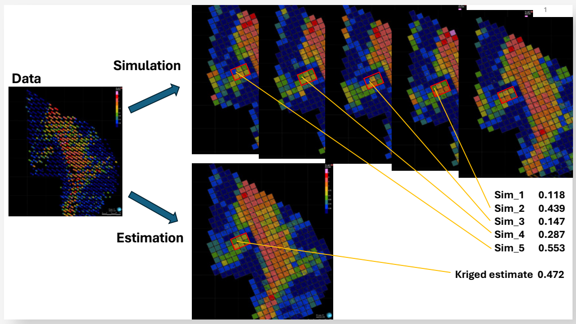
Estimation calculates the single most likely value of a variable, such as a metal grade, for a specific location (point or block). The value is based on a weighted average of selected local samples, with the weights depending on the type of estimator.

Kriged estimators use a variogram to calculate a set of weights that minimise estimation error. Estimated models are well-suited for tasks where an unbiased localised prediction is fit for purpose: mine planning, reporting, and reconciliation.

The trade-off is smoothing. Local highs and lows are moderated, and the resulting estimate is less variable than the underlying deposit it intends to represent.

Conditional simulation generates multiple equiprobable realisations

Rather than producing one best estimate, conditional simulation generates multiple equiprobable realisations that honour the sample data and reproduce key statistical properties of the variable, including its distribution and spatial continuity. Each realisation is one plausible version of the deposit. Together, they form an ensemble that can be used to assess variability and uncertainty.



Conditional simulation reproduces variance of the input data, including the high grade tail common in many mining deposits. In contrast, kriging generates results with a reduced variance, under-representing the highest and lowest grades.

The difference matters because the two approaches support different kinds of decisions. Estimation is useful when the goal is to produce a single representative model. Conditional simulation is useful when local variability matters and uncertainty needs to be understood in terms of risk.

Why conditional simulation is becoming more practical

Conditional simulation has been part of the geostatistical toolkit for decades, and its value in modelling uncertainty is well established. Yet in practice, it has not been widely adopted. There are several reasons for that.

Conditional simulation has traditionally been slower and more computationally intensive than estimation. It has often required specialist software, expert-led workflows, and significant manual effort to generate, validate, and interpret results.

In many organisations, it has kept conditional simulation confined to advanced studies rather than making it part of routine geological decision-making. The issue has not been whether conditional simulation is useful but whether it is practical.

That is changing as integrated workflows, cloud computing, and improved validation are reducing some of the barriers that historically made conditional simulation difficult to apply. Instead of relying on disconnected tools, specialist scripting, or long processing times, geologists can now access conditional simulation in a more streamlined environment that fits more naturally within existing modelling workflows.

Geological decisions increasingly need to account for the estimated value and the uncertainty around it. A single estimate remains appropriate for many purposes, including planning, reporting, and reconciliation. But where local variability materially affects confidence, classification, or downstream outcomes, the range of plausible results becomes important as well. Conditional simulation gives geologists a way to see and use that uncertainty more directly.

Where and when to use conditional simulation

Whether conditional simulation can be applied appropriately depends on the dataset, the domain, and the decision context.

Key factors include:

Data density:
Whether there is enough data to support simulation credibly

Modelling scale:
Whether the scale of the problem is appropriate for the available data

Domain definition:
Whether an acceptable degree of statistical homogeneity is present within a geologically coherent volume

Where conditional simulation can add the most value

Conditional simulation adds the most value where local variability matters and uncertainty has direct consequences for decisions. This includes mineral resource estimation, near-mine modelling, and production-related workflows where the decision depends not just on an average value, but on the range of plausible outcomes around it.

For example, two stopes may carry the same estimated grade but not the same level of risk. One may show a narrower range of plausible outcomes, while the other may be much less certain. Conditional simulation makes that difference visible, helping geologists and downstream teams better understand confidence, prioritise acquisition of additional data, and make more informed decisions about sequencing or planning.

Used in the right setting, conditional simulation provides a stronger basis for assessing variability, understanding confidence, and supporting decisions such as classification or planning. It does not replace estimation. It complements it by showing the uncertainty behind a single estimate.

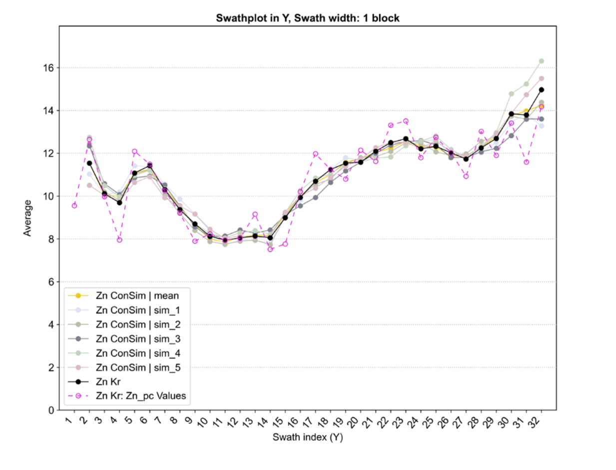
For that uncertainty to be interpreted meaningfully, however, the simulation domain must be coherent enough for one set of statistical assumptions to apply across it. In practice, that depends on the assumption of stationarity.

Stationarity in practice

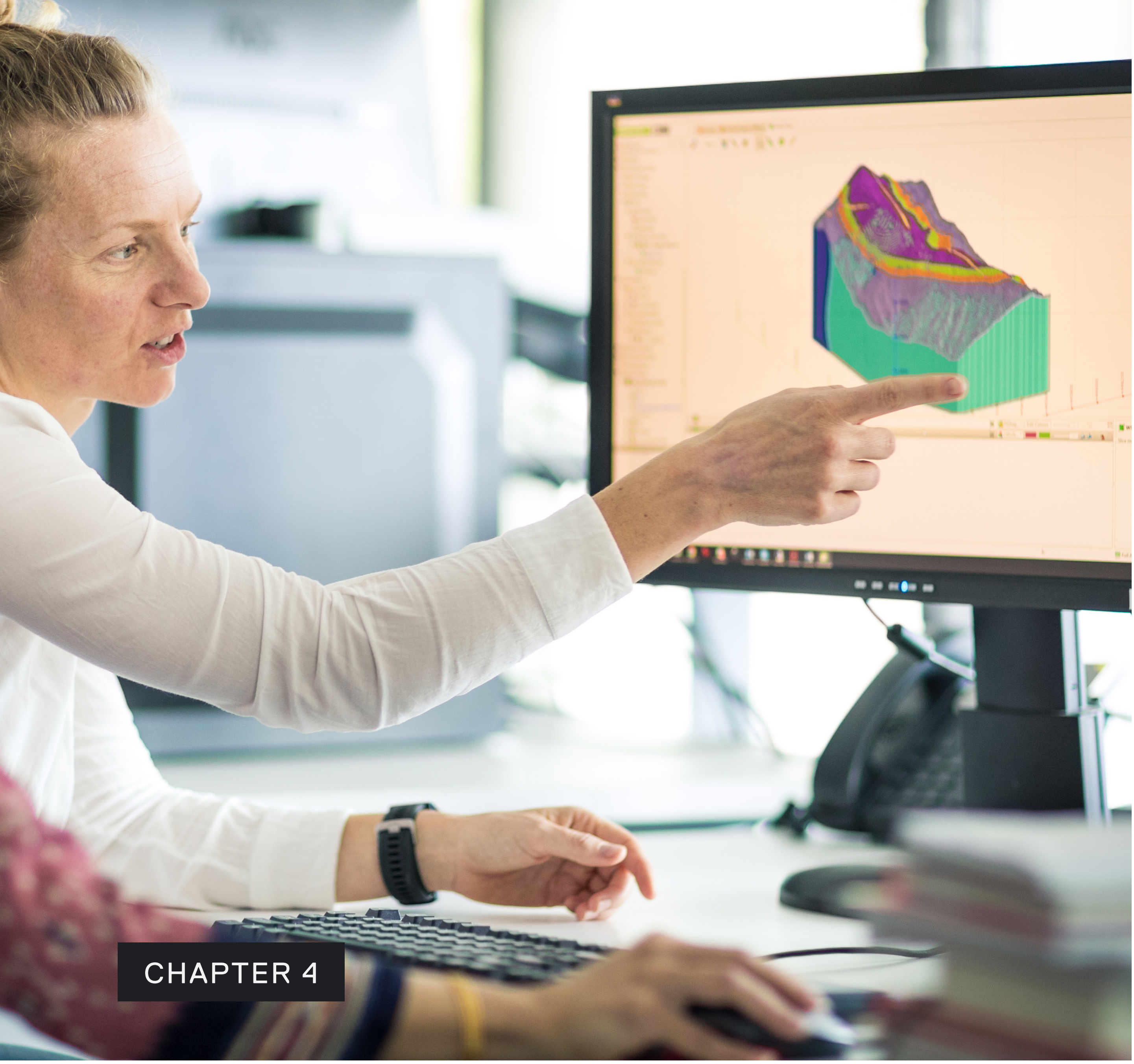
In practical terms, stationarity means the variable being modelled behaves in a reasonably consistent way across the simulation domain, so that one set of statistical assumptions can be applied across that space. It does not mean geology is uniform. It means the domain is coherent enough for simulation to be applied meaningfully.

Conditional simulation is generally more sensitive to domain assumptions than routine estimation workflows. Where there are strong trends, unresolved boundaries, or rapidly changing geological behaviour within a single domain, results may still be generated, but that does not mean the simulation is geostatistically appropriate or that the outputs should be accepted at face value. In these situations, more care is needed in how the domain is defined, how the method is used, and how the results are interpreted.

Additional judgement may be needed where datasets are sparse, domains are larger or more heterogeneous, trends remain unresolved, or domain boundaries are uncertain. The same is true where the consequences of error are high.



Conditional simulation swath plot



CHAPTER 4

Conditional simulation workflow in Leapfrog

Historically, conditional simulation has often sat outside everyday geological practice. It has typically required specialist software, manual or scripted processing, and fragmented workflows.

Seequent's conditional simulation workflow takes a different approach. In practical terms, the workflow brings together four things.

01 A connected workflow from modelling to simulation

In Seequent's workflow, Leapfrog Geo provides the geological modelling environment, Leapfrog Edge provides the mineral resource estimation workflow, and Evo provides the cloud computing, versioning, and storage needed to run the simulation efficiently.

- Users work in Leapfrog Geo and Leapfrog Edge to define domains, prepare inputs, configure the simulation, and review the results.
- The compute-intensive simulation step is initiated in Edge and then sent to Evo, where cloud processing happens more efficiently than on a local desktop workflow.
- The results are returned to the Leapfrog environment, where they can be reviewed, validated, and used in downstream workflows.

This is a meaningful shift from the traditional status quo. Instead of exporting data into a separate package, relying on disconnected tools, or managing specialist scripts outside the estimation workflow, geologists can carry out simulations in an environment that is already familiar and directly connected to the rest of their modelling and estimation work.

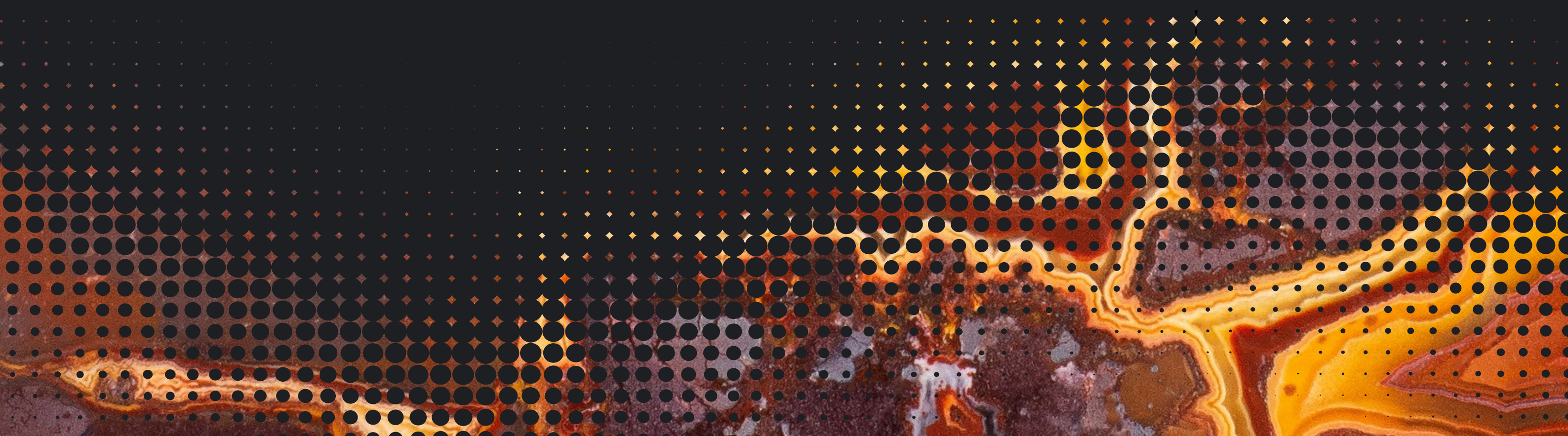
02 Faster simulation through cloud compute

One of the main barriers to the broader use of conditional simulation has been speed. Generating multiple realisations is computationally intensive, and traditional desktop-based approaches can be slow enough to make simulation impractical for routine use.

Seequent addresses this by using Evo's cloud-based compute layer to handle the heavy processing. That makes it possible to generate simulation ensembles much more efficiently, without relying on local hardware or interrupting the rest of the modelling workflow. In practical terms, this shifts simulation from something that may be technically possible but operationally awkward into something that is much more usable in resource estimation practice.

What is Seequent Evo?

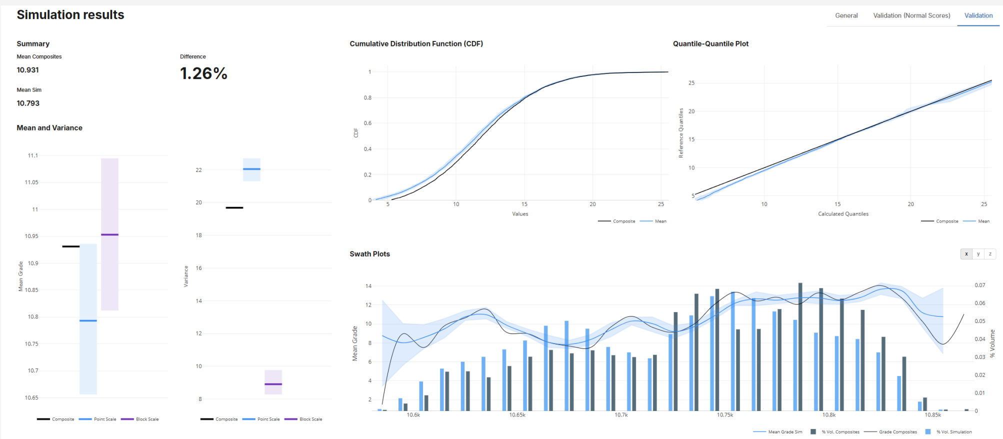
Seequent Evo is a geoscience data and compute platform that enables integrated workflows and collaboration across Seequent and third-party products. It powers geoscience solutions for data processing, modelling, and insight generation. This drives innovation and enables users to continuously improve their workflows and business with open APIs and data.



03 Validation built into the workflow

For simulation to support real decisions, users need confidence that the ensemble is behaving sensibly and is appropriate for use.

That is why validation is built into Seequent's workflow rather than being an afterthought. The workflow is designed not only to generate simulation ensembles, but also to provide checks and reporting that help users assess whether the results are robust enough to interpret and apply. Historically, much of the effort involved in simulation has gone into setup and validation before the outputs can be used confidently. By making validation more explicit and operational, Seequent helps users move more efficiently from simulation to interpretation.



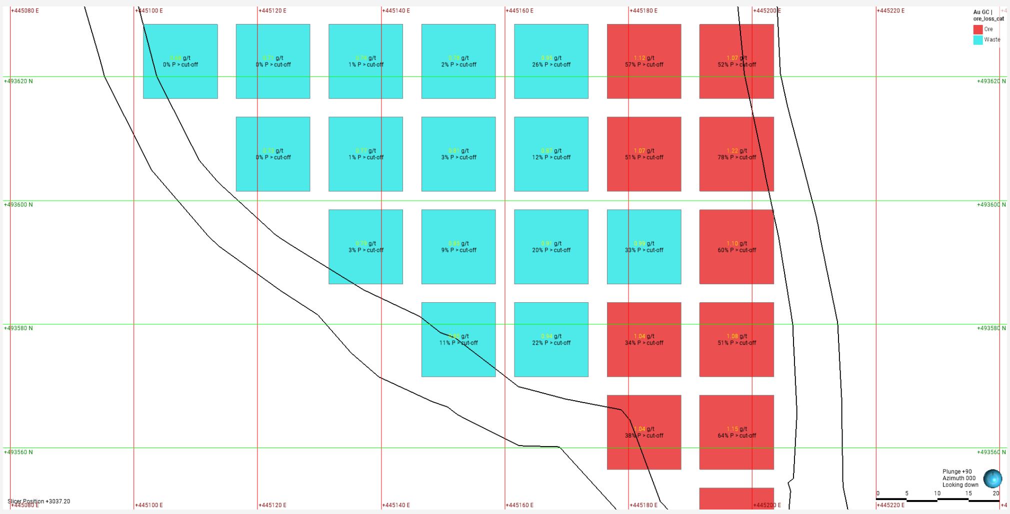
Evo-hosted validation dashboard compiles summary statistics and plots.

04 Outputs that support practical decisions

Seequent's workflow is designed to support practical outputs that help geologists use uncertainty in context.

In grade control, for example, the workflow can combine simulated grade variability with economic inputs such as mining cost, recovery, and cut-off criteria to support ore-waste classification. Instead of relying only on a single deterministic estimate, users can incorporate uncertainty directly into the classification decision.

This is more useful than simply producing a stack of realisations and leaving the user to determine how uncertainty should influence the decision.



Conditional simulation of ore probability

Looking ahead

Conditional simulation is part of a broader shift toward making uncertainty more usable in geological workflows. Seequent's focus today is on giving geologists a practical way to generate, validate, and apply simulation results within Leapfrog and Evo. The real opportunity is to make uncertainty easier to interpret and more useful in decision-making.

Learn more about Leapfrog Edge

Visit seequent.com/leapfrog-edge to explore product videos, customer success stories, or request a free 14-day trial or live demo.

Learn more

Understand the underground to build a better world.

Seequent is evolving the way organisations work through better subsurface understanding.

As the world leader in subsurface earth-modelling, analysis and data management and collaboration software, Seequent is at the forefront of building a collective understanding of the Earth.

We hire amazing people who collaborate with our customers to find technology solutions to their challenges that deliver more positive outcomes for a better world.

As The Bentley Subsurface Company, Seequent connects our natural environment with the built world so organisations can manage the impact of their projects at every stage.