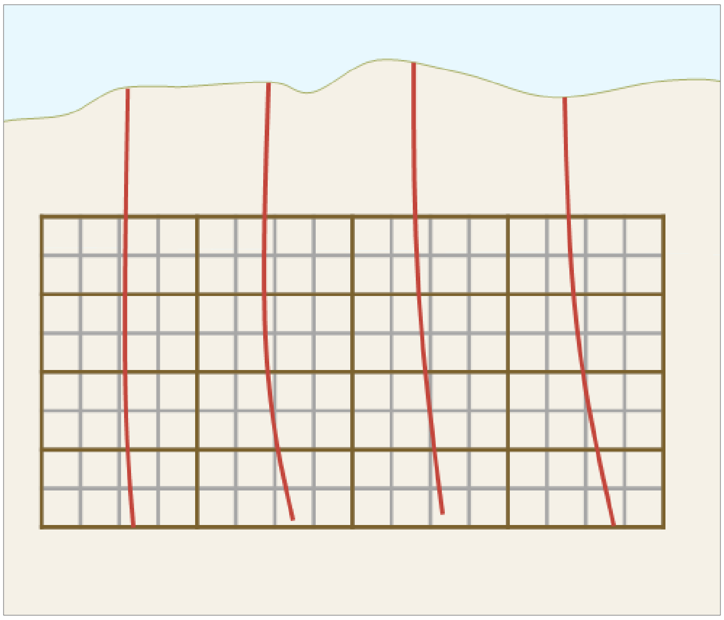
White Paper



Which block size for mineral resource estimation

How to choose a relevant estimation support size

Which block size for mineral resource estimation

How to choose a relevant estimation support size

Find the right compromise between mining constraints and the estimation precision required.

A key aspect of mineral resource estimation (MRE) is the definition of the block dimensions used to estimate the deposit attributes. Several, potentially conflicting objectives are at play in determining MRE block dimensions:

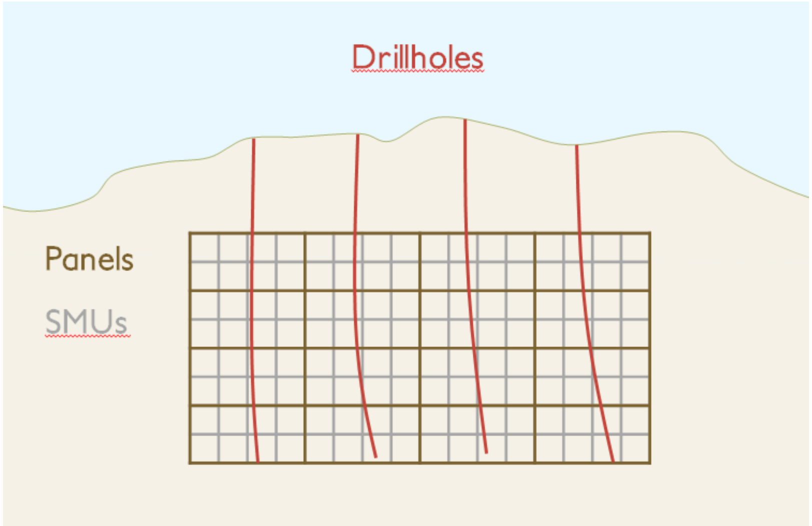
1. the motivation to maintain what is perceived to be the necessary level of geometrical precision in the definition of the geological envelopes used to control the estimation;
2. the ability to predict how the deposit will respond to selectivity constraints imposed by the nature of the mining method and the size of the mining equipment; and finally,
3. the aspiration to maintain the highest level of estimation precision given the density of information available at the time.

As always we are looking for a satisfactory compromise: we expect an estimate that allows us making decisions upon volumes that are representative of the physical reality of the operation but are aware that the density of information available at the time of estimation probably does not warrant the direct estimation of such volumes. A high-level review of the acceptable strategies to find such a compromise is discussed below.

Drillholes, SMU's, Panels… Which support to which end?

Is your estimation on the right support size?

When making estimates in mining applications we often wish to map the spatial distribution of the mineral attributes on the basis of block support rather than sample support.



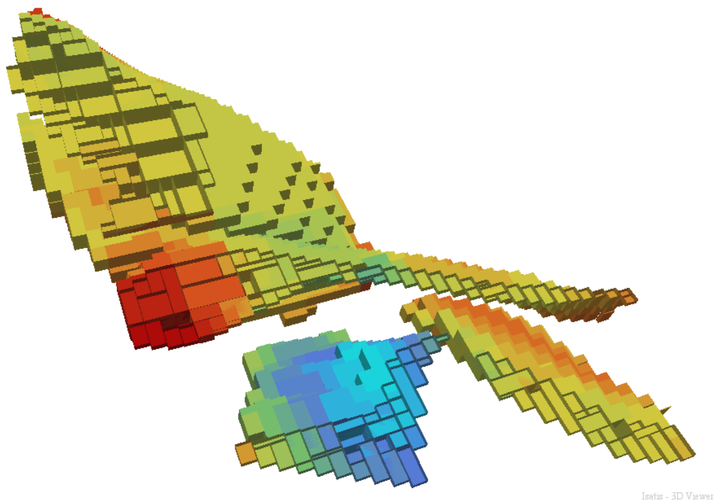
At the exploration or feasibility stages of a project, the direct linear estimation of SMU's has low precision. Which may result in an undue level of uncertainties in project economics assessment.

The SMU or selective mining unit refers to the minimum support upon which decisions (in particular ore/waste allocation decisions in open pit situations) can be made. The SMU, which by definition is **larger** than the support the information is collected on, is usually **significantly smaller** than the sampling grid dimensions, in particular at exploration/feasibility stages. As a consequence, the direct linear estimation of such **small blocks** has very low precision (literature from bona fide experts abound on the topic: Armstrong and Champigny, 1989; David 1988; Journel, 1985; Krige, 1997; Matheron, 1984; Rivoirard, 1994). A direct serious consequence of directly interpolating small blocks is that the grade-tonnage curves are **severely distorted** i.e. prediction of the content of an attribute above a cut-off based on these estimates can be quite distant from reality. The subsequent assessment of project economics based on these estimates will thus carry an undue level of risk.

Estimating at the SMU scale

The **first** (and fairly safe) strategy when faced with such a conundrum is to address the geometrical problem separately from the issue of estimation precision. The idea is to establish the geometry by relying on an elementary volume that has to maintain some form of pragmatism and then populate the different small cells with estimates migrated from parent blocks, with dimensions compatible with the sample grid spacing. If one tackles the issue that way, two options are available to report the estimates:

1. Report at the level of the parent blocks and use the (sub-celled) geometrical model to calculate parent block proportions (volume partials); or,
2. Report at the elementary level (using the estimates migrated from the parent blocks) which leads to a model easier to manipulate (single grade model per attribute) and visualise.



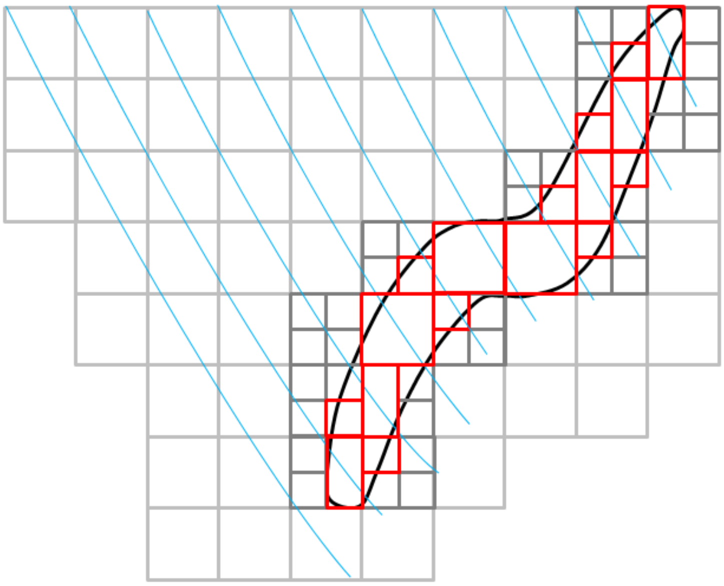
To get estimates at the SMU scale, a first solution is to infer them from the more precise estimates of larger blocks, the dimensions of which being compatible with the sample grid spacing.

The treatment of the sub-cell geometry by modern software packages can take different forms: it can use fixed block dimensions (as in Gems® or Geovariances' Minestis© software) or rely on sub-cells of varying dimensions like in Datamine®. The optimal treatment of the parent block estimation to populate these geometries can be accessed in various software packages but nowhere is it more efficient than in Isatis©, thanks to its unparalleled collection of recoverable resource estimation methodologies coupled with advanced localisation and migration capabilities. The reader is referred to Geovariances "How to estimate Datamine® Sub-Block Models" for further details on the topic (download the flier at http://link.geovariances.com/sub-block-model-estimation).

While estimation of very large blocks, say similar in dimensions to the sampling grid, will result in estimation of a higher precision (in keeping with the precepts of Kriging Neighbourhood Analysis – KNA, as implemented in Isatis© and Minestis©), it also implies a lower level of selectivity, incompatible with the one that can be achieved at mining stage.

The above situation is not restricted to open pit situations and can also be met in underground situations. For narrow-vein estimations for example, the pinching and swelling of the vein complex geometry can safely be handled from an estimation viewpoint by resorting to 2D estimation of thickness and accumulation variables. But spatializing such an estimate in 3D is a different issue and one where resorting to a sub-celling approach can be tempting, and sometimes adapted, provided:

- the estimates used to populate these sub-cells remain coherent,
- and the level of geometrical precision of the model remain pragmatic and consistent with the real level of mining selectivity.



Narrow vein geometry and treatment with subcells.

A second solution is to implement non-linear geostatistics for recoverable resource estimation whose advantage is to overcome the issue of over-smoothing induced by linear estimation.

Estimating recoverable resources at the panel scale and localising

A **second** solution has been developed by the geostatistical community more than 30 years ago. It overcomes the issue of over-smoothing induced by the linear estimation of large blocks through the development of non-linear geostatistics giving access to recoverable resource estimation. Recoverable resource estimation specifically aims at deriving the local conditional distributions (conditional to the neighbouring information) of SMU's (selective mining units or small blocks) within larger estimated blocks (referred to as panels).

The non-linear approach allows estimating the proportion of SMU-sized blocks above a specified cut-off, within a panel.

There are many methods now available (all accessible in Isatis©) to make local (panel by panel) estimates of such distributions, some of which are:

- Disjunctive Kriging;
- Multiple Indicator Kriging;
- Probability Kriging;
- Lognormal Kriging;
- Multigaussian Kriging;
- Multivariate Uniform Conditioning;
- Residual Indicator Kriging; and,
- Service Variables.

Case study for a porphyry copper-gold deposit in Peru

Multivariate uniform conditioning and localised multivariate uniform conditioning (LMUC) have been applied in the framework of **production reconciliation** of the Gold Fields Cerro Corona porphyry copper-gold deposit in Peru.

The reconciliation study compared the long term LMUC mineral resources model which is invariably based on drilling data on a relatively large grid to the corresponding production blast-hole grade control model, as well as the final plant production.

The results showed the narrowing of the observed confidence limits:

• the central 80% confidence limits of the **monthly production errors** were -12%/+10%, -6%/ +14%, and -8%/+8% for tons, and gold, and copper grades respectively, and +6%/+2%/-7% on a **quarterly basis** for tons, and copper and gold grades respectively.

• the average percentage errors were of −1%/+3% for the plant production reconciliations on a **macro or long term production basis**.

Assibey-Bonsu, W. & al, 2014*. Production reconciliation of a multivariate uniform conditioning technique for mineral resource modelling of a porphyry copper gold deposit. The Journal of The Southern African Institute of Mining and Metallurgy, Volume 114, March 2014, p.285-292.*

The choice to resort to one method or another should be guided by tests helping characterise the actual grade architecture of the deposit: in other words the solution chosen should be adapted to the problem at hand, not the other way around.

Non-linear estimation provides **the solution** to the "small block" problem by stating that we cannot precisely estimate small (SMU-sized) blocks by direct linear estimation but can however estimate the proportion of SMU-sized blocks above a specified cut-off, within a panel.

This is all the more true as we can also now get a sense of how these distributions could be distributed in space thanks to the advance brought by **localisation** procedures. A very important development over the past decade has indeed been made following Abzalov's (Abzalov, 2006) proposition in 2006 to localise the grade tonnage curves obtained by Uniform Conditioning to allow manipulating single grade models defined at the resolution of SMU sized blocks. The Localised Uniform Conditioning (LUC) method has been implemented in Isatis© since then and has become one of the more common approaches for grade estimation when data spacing is broad in comparison with the estimated block size as the method produces accurate grade tonnage functions which are in a good accordance with volume-variance relationship principles. The ranking that is used in the localisation procedure is more or less effective depending on the level of continuity of the attribute, and can be quite misleading in the presence of moderate to high nugget effect (which seems realistic: the procedure, whilst being very appealing, should by no means alleviate the requirements for geological and grade control systems at mining stage!).

This localisation is now also accessible in Minestis©. The package offers a coherent processing of in-situ and recoverable resource estimates by tying the geometrical definition of the envelopes using the elementary volume given by the SMU's. Nothing prevents the user from using small SMU's to increase the level of geometrical precisions in the definition of these envelopes (at the risk of course of reducing performance and rendering the models locally devoid of any practical meaning).

No one will dispute the fact that these localised models offer **key advantages for visualisation and reporting purposes**, and Geovariances is a strong supporter of using such models, as long as they remain practical, realistic and robust.

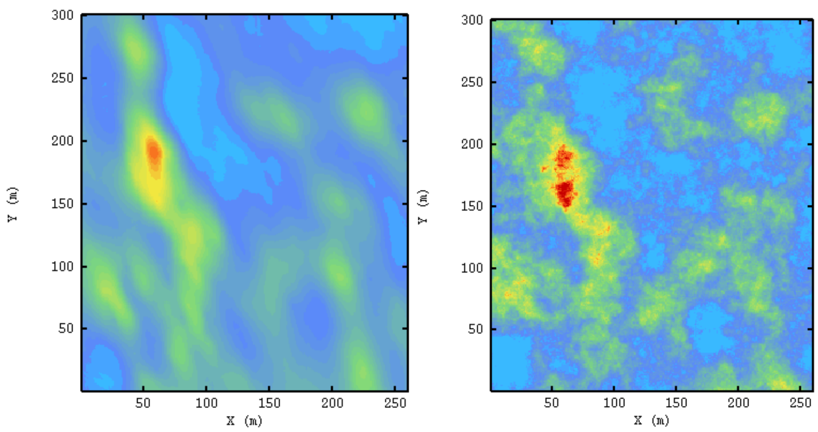
Note that the localisation procedure in LUC can also be used for other purposes. The reader is referred to one of Geovariances' success story where an interesting and innovative use of the methodology was described to allow the representation of vein proportions estimated by Indicator Kriging at panel level via Indicator values (0-1) assigned to SMU's belonging to each panel (see http://link.geovariances.com/ik-luc).

Conditional simulations provide a relevant alternative answer for SMU estimation.

Conditional simulations

The way to treat the representation of the deposit geometry at elementary levels cannot make the economy of presenting a **third** solution, the one offered by conditional simulation.

Simulations (of geology and/or grade as performed in Minestis©) offer an ideal platform to deal with the estimation, reporting and visualisation of **recoverable** resources at the scale of SMU's. It sometimes happens to be the only practical path towards such an estimation (Bertoli, Deraisme and Epinoux, 2014). The price to pay being increased time, additional care required to test hypotheses and validate the production of simulated models, increased disk-space, and the need for aptly designed post-processing facilities. That may seem a hefty one to pay but one made possible by current computer power and newly designed post-processing facilities (like scenario reduction as implemented in Isatis (more info at http://link.geovariances.com/simulation-reduction), where one can select a manageable subset of realisations to fully capture the space of uncertainty characterised by the full set of realisations).



Estimated model (left), versus simulated model (right)

Conclusion

As stated in introduction, defining the size of the blocks used for estimation and reporting of mineral resources is by no means a trifling issue and one that should always be treated with utmost care and diligence. Modern software packages are all offering tools to help with that decision, and Geovariances expert geostatistical toolbox Isatis© and dedicated MRE solution Minestis© can certainly provide a wide range of possibilities to deal with that issue. In the end, one should ensure the block size remains practical, adapted and most of all robust so that it doesn't give a false sense of selectivity or precision that is simply not attainable given the density of information and potentially severely misleading.

Visualisation and ease of reporting, although crucial considerations, should by no means take the lead over robustness and reliability of the figures being reported.

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Geovariances
Where no one has gone before

Who is Geovariances?

Geovariances is an independant software vendor specialized in geostatistics. We have over 45 staff, including expert mining consultants and geostatisticians.

Our reference software, Isatis, is the accomplishment of 25 years of dedicated experience in geostatistics. It is the global software solution for all geostatistical questions.

Through a simplified and secure geostatistics-based approach, Minestis offers a fast and easy-to-use workflow for efficient and reliable domain modeling and resource evaluation.

Other technical specialties

Geovariances is world leader in developing and applying new and practical geostatistical solutions to mining operations. We have strong experience in all commodities, and have gained trust from the biggest international companies.

Our expertise is in applying geostatistics to resource evaluation. Our services are through consulting, training, and software.

Our expertise

Geovariances has 30 years of experience in applying linear and non-linear geostatistics (and more recently Localised Multivariable Uniform Conditioning) to orebodies worldwide, and in training mining staff in their applications.

We can provide a unique expertise through both our French and Australian offices.

Geovariances is dedicated to applied geostatistics and has set the standards in geosciences, providing the mining industry with Isatis© software for more than 20 years, and now Minestis©, the dedicated software to MRE.

For more information

Let us help you optimise the accuracy of your predicted recoverable resource estimates and access the information you have available regarding recoveries predicted at the mining (SMU) scale.

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