

Applicability of machine learning in agile decision making in open pit dewatering: A case of study in Antamina mine (Peru)

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» Motivation: why to dewater?

- ❑ Because the presence of water (mines below “water table”) can:
 - Complicate access within the pit and operational times
 - Compromise the physical stability
 - Changes the resistive and driving forces of slopes
 - Pore pressure reduces effective stress and shear strength
 - Can lead to landslides and loss of sections of the pit, including associated risks to personnel
 - Cause detrimental effects on the mobility and hauling
 - Increases weight of the ore
 - Tyre wear
 - Reduces passability
 - Cause malfunctions with explosives (increases blasting)
 - ...and others
- ❑ At the end, water increases costs dramatically
- ❑ A proper solution is to anticipate water problems, before and while, pit development, with foresight and planning of a proper dewatering



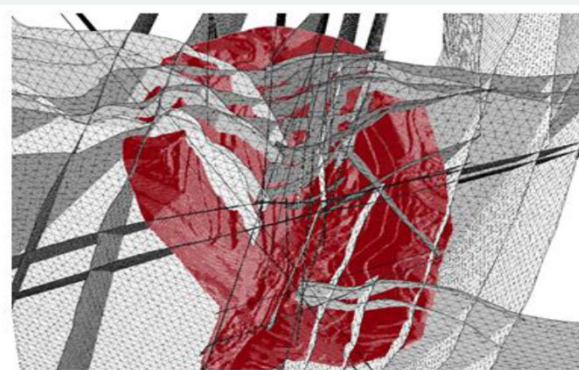
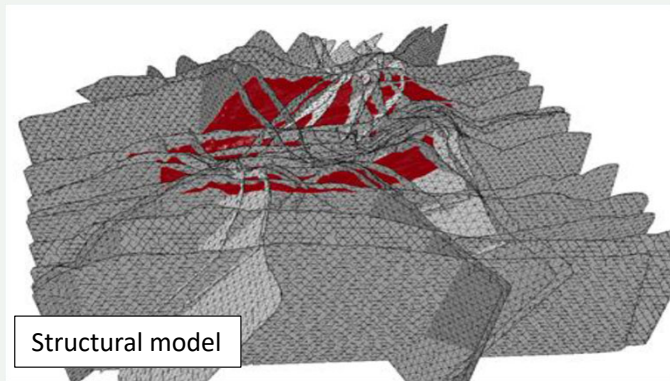
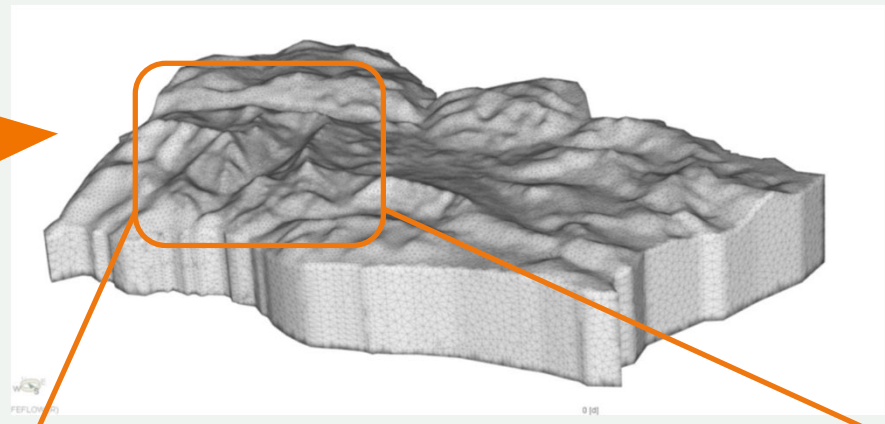
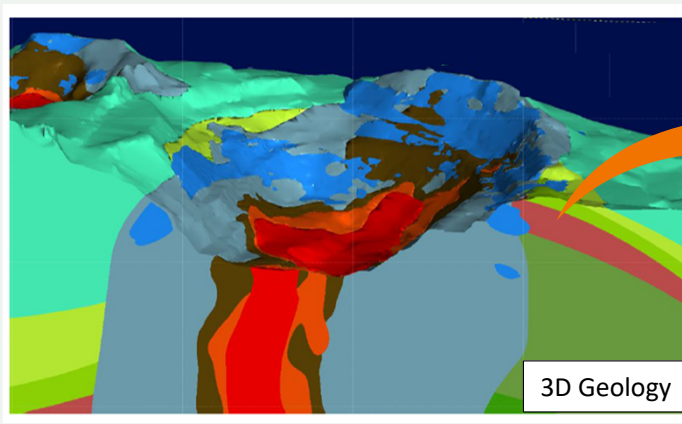
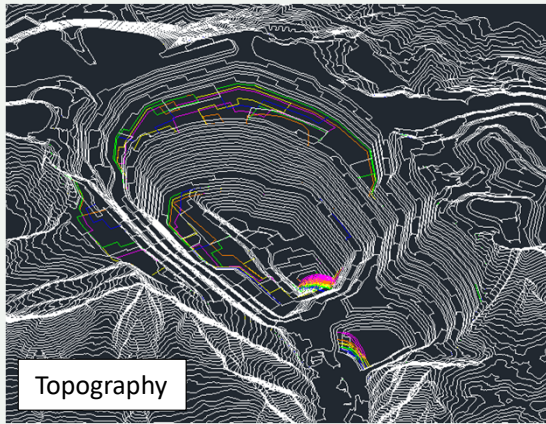
» A case of study: Antamina mine



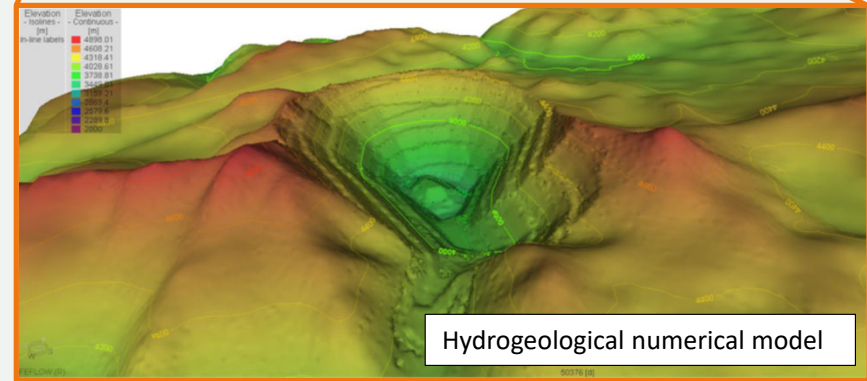
Video of the Antamina pit, provided by Antamina



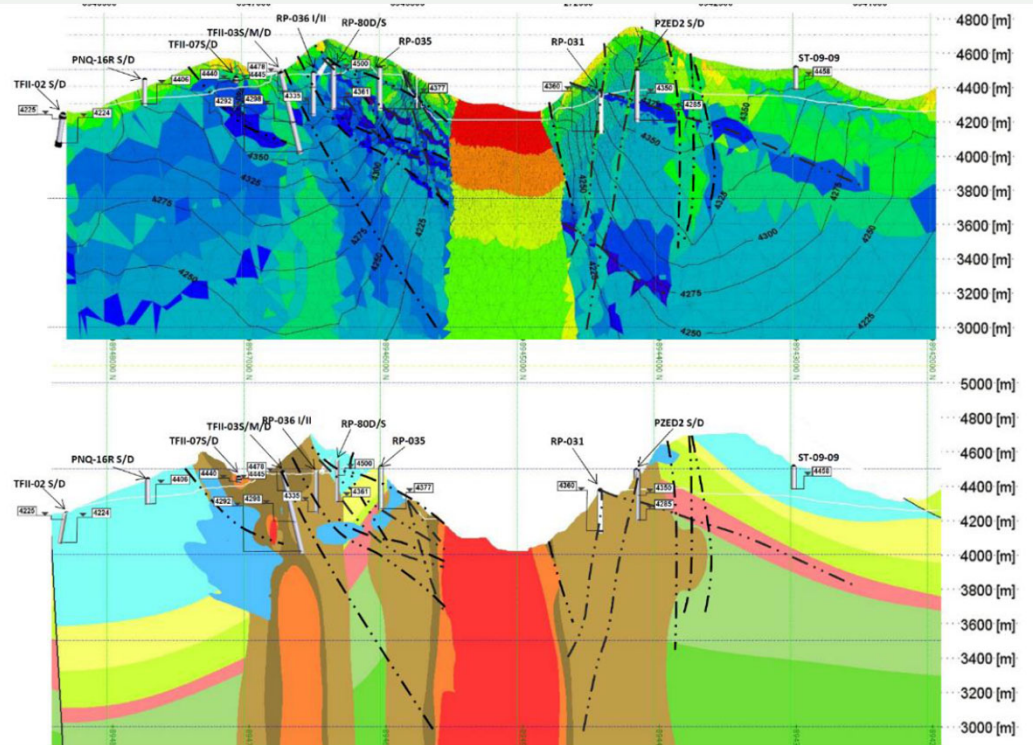
» On the hydrogeological foresight and planning



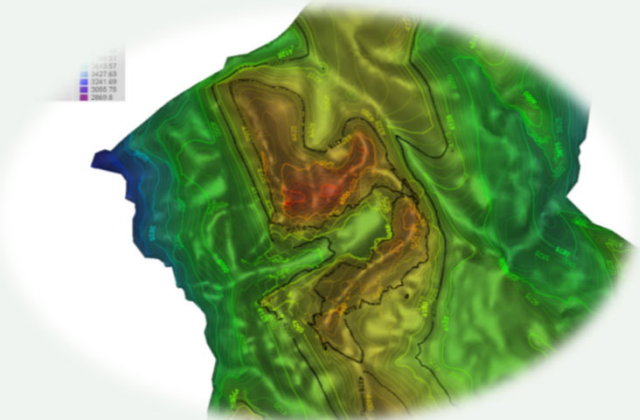
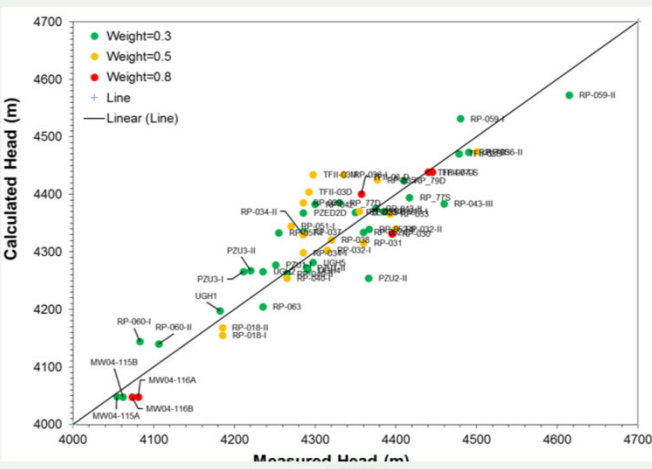
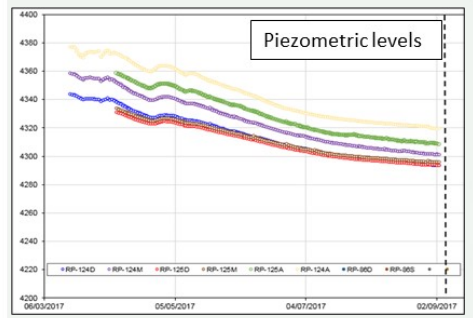
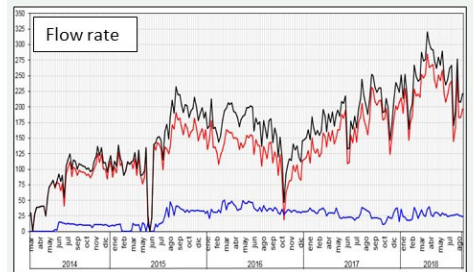
Images courtesy of Antamina



» The process of simulation: it is really a complex and hard task



Images courtesy of Antamina



»» The 'pain': too many changes

- ❑ Changes occur continuously affecting forecasting and new predictions become to be reevaluated:
 - Geological (and structural), and thus hydrogeological behaviour
 - Climate conditions
 - Changes the recharge
 - Pore pressures
 - Run-off
 - In the ore grade led to changes in mining plan, so excavation changes
 - Strategical planning predictions and scenarios can be needed
 - Malfunctions while operations (pumping, energy boosters,...)
 - others
- ❑ At the end, there is a need to re-evaluate predictions, usually it is needed a quick foresight (often weeks not months)

»» **We set ourselves a goal: how to achieve fast and agile forecasting?**



» From ML towards a hybrid methodology – why?

2021

Database Generation
 Statistical study
 Algorithm Selection
 Algorithm Training and Verification
 Algorithm Validation (blind predictions)
 Applicability and opportunities



2022

CNN ML tool
 (convolution Neural
 Network arch.)
 development
 and validation



2023

Hybrid Approach
 Analytical solution on wells
 interference
 Recurrent Neural Networks (RNN)
 Dashboard / web_app

2024

Hybrid Approach



Neural Hierarchical Interpolation for Time Series

- State-of-the art (2022)
- Sequence-to-sequence models
- Allows to capture patterns at different scales
- Uses ANN instead of RNN or transformer models

Machine Learning | DataInterview.com

Linear Regression Predicts using weighted sum of features	Logistic Regression Predicts probability, used for binary classification	Decision Tree Tree-like model segregating data based on feature thresholds	Neural Networks Layers of interconnected nodes that resembles the human brain	PCA Reduces dimensions, retains most data variance	Support Vector Machine Maximizes margin between class boundaries
Random Forest Averaging of outcomes from multiple decision trees	Naive Bayes Probabilistic classifier using the Bayes Theorem	Gradient Boosted Trees Sequentially trained trees where samples weighted based on errors	K-Nearest Neighbor Classifies using nearest neighbor votes	K-Means Partitions data into k similar clusters	Markov Chain Model Probabilistic transitions between states based on current state



» Could a machine learning approach help to be more agile?

Or even could we combine ML approaches with numerical or analytical models to build a workflow that improves the prediction of groundwater dynamics?

	Advantages	Disadvantages
Numerical and Analytical models	<ul style="list-style-type: none"> • Interpretability • Consistency on unseen or new scenarios • Well know and used for a long time 	<ul style="list-style-type: none"> • Difficult or increasingly complex to include all the relevant processes • Constrained to the underlying conceptualization
Supervised Machine Learning	<ul style="list-style-type: none"> • Can extract complex patterns from data • Inference is quicker 	<ul style="list-style-type: none"> • Needs huge information (big data) and with the best quality as possible • May not generalize well to unseen data

Methodology: hybrid approach

Variables

- $h_0(t)$ $Q_0(t)$
- $h_1(t)$ $Q_1(t)$
- $h_2(t)$ $Q_2(t)$
- $h_3(t)$ $Q_3(t)$

Analytical Model

$$h(\mathbf{x}, t; Q)$$

$$h_0^*(t)$$

$$h(\mathbf{x}, t) = \sum_{j=1}^N \int_0^t dt' \frac{\exp\left[-\frac{(\mathbf{x}-\mathbf{x}_j)^2}{4\frac{T}{S}(t-t')}\right]}{4\pi T(t-t')} Q_j(t')$$

$$\underbrace{\quad}_{T \quad S \quad h_0}$$

Variables

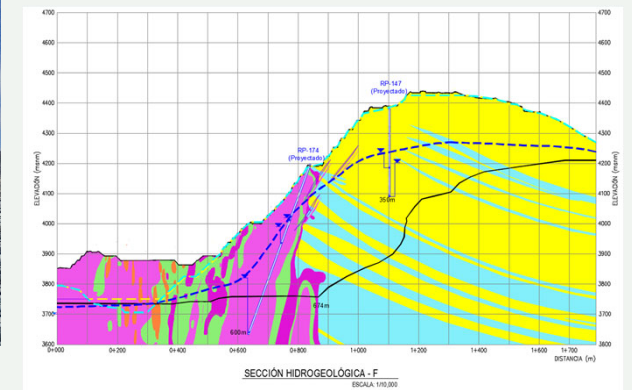
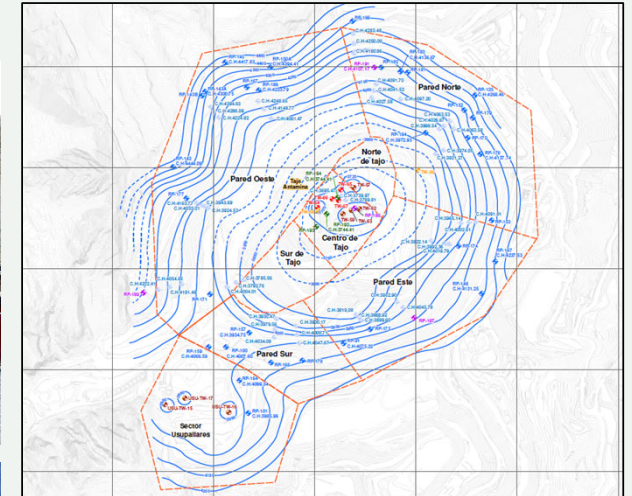
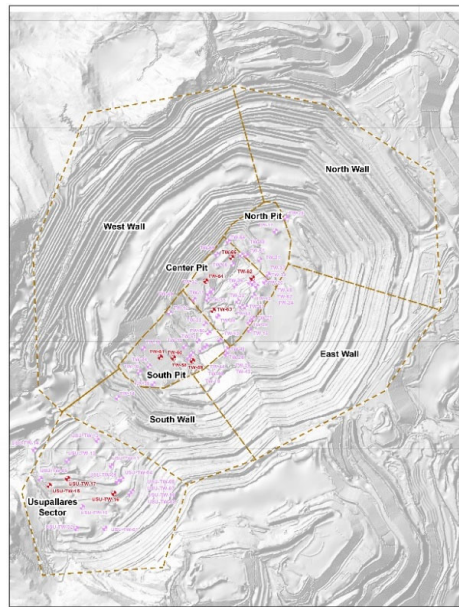
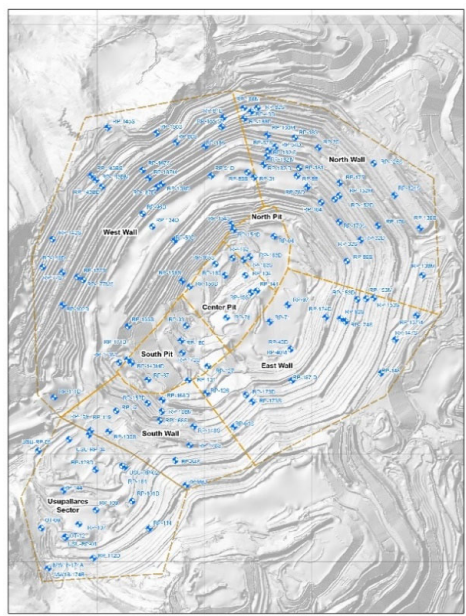
- $h_0(t)$ $Q_0(t)$ $h_0^*(t)$
- $h_1(t)$ $Q_1(t)$ $h_1^*(t)$
- $h_2(t)$ $Q_2(t)$ $h_2^*(t)$
- $h_3(t)$ $Q_3(t)$ $h_3^*(t)$

ML Model

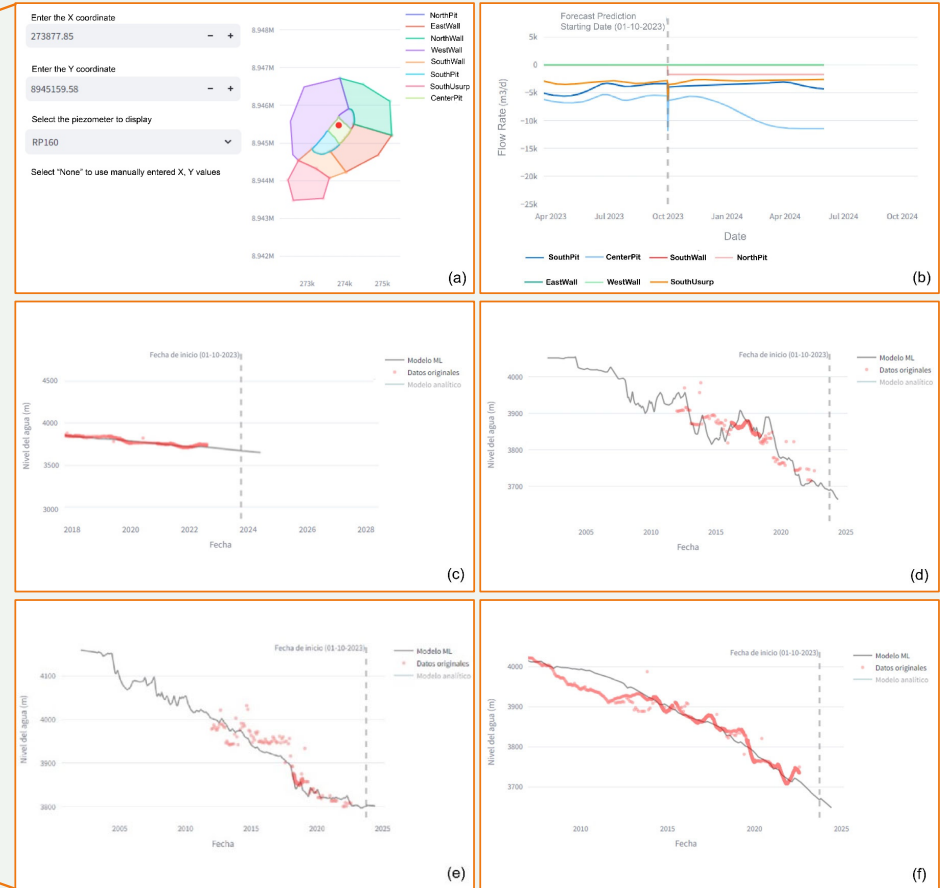
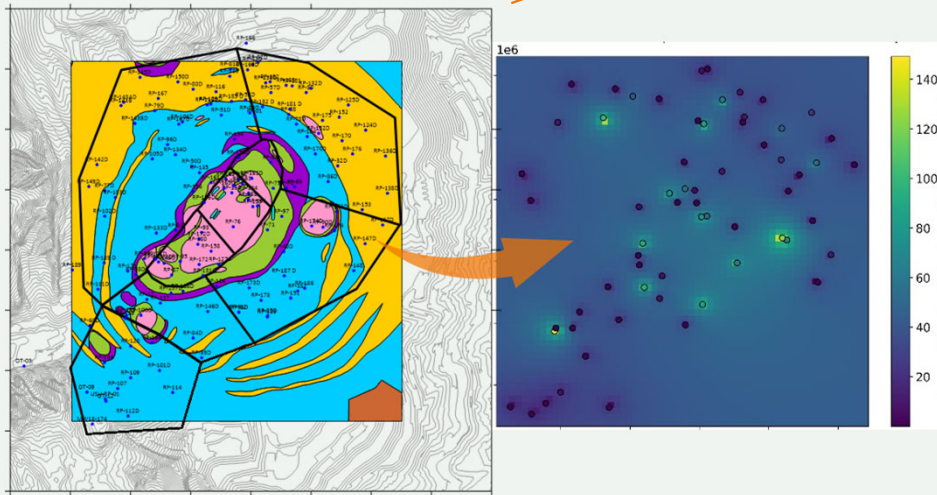


$$h_0^f(t)$$

» Our case of study: on the hydrogeological conceptual model support



» Our case of study: on the data treatment as model input



» A quick demo view on the use (sorry for the Spanish)

Webapp - Antamina

Esta webapp tiene dos modos de funcionamiento:

- El **modo científico** permite explorar los resultados de la solución analítica y el corrector neuronal.
- El **modo usuario** permite al usuario introducir datos de bombeo para obtener una predicción de los niveles.

Escoge un modo

Modo científico

Modo usuario

Predicción de niveles en un campo de bombeo usando IA

Esta webapp muestra los resultados de una solución integrada de inteligencia artificial para predecir la evolución de los niveles piezométricos en un campo de bombeo.

La solución permite hacer una estimación de la evolución de los niveles piezométricos dado un plan de bombeo futuro. Para ello, se usa una combinación de una **solución analítica** o de interferencia de pozos optimizada y un **corrector neuronal** que mejora la precisión de la solución analítica.

Para construir los dos modelos, se han usado series históricas de datos de bombeo y de niveles piezométricos, además de información de zonas geológicas y registros de precipitación.

Seleccione el piezómetro a visualizar

RP131

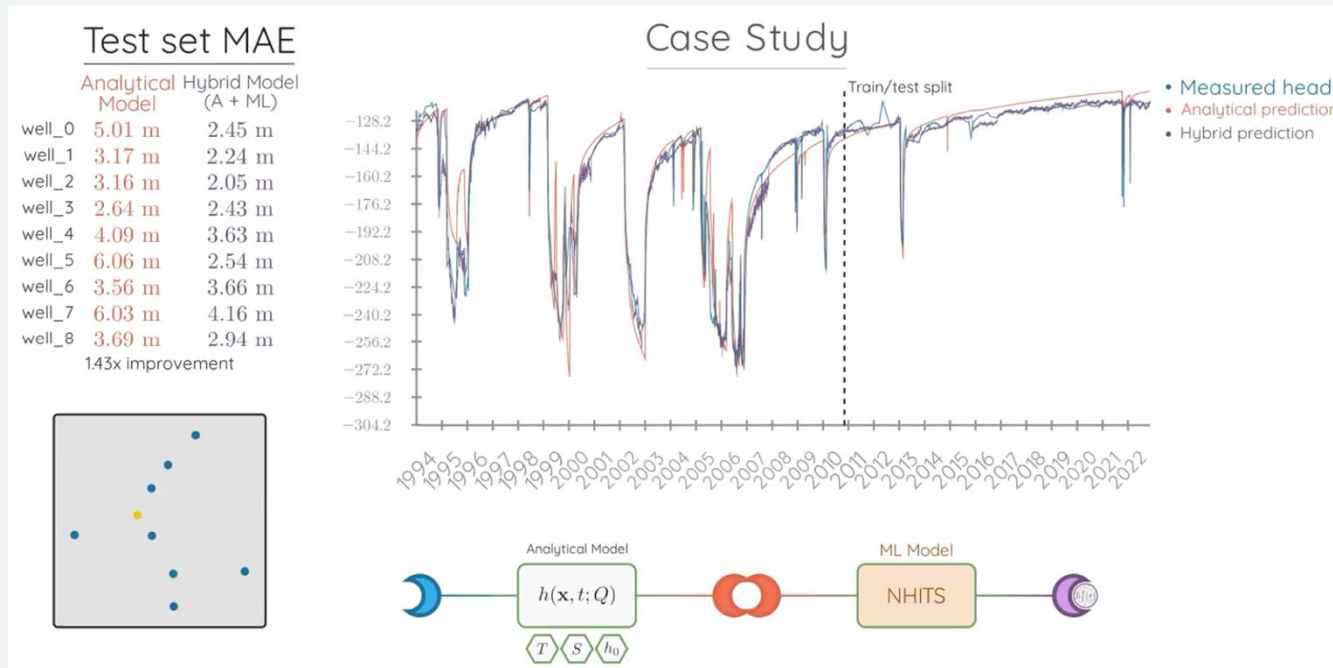
Activar corrector neuronal

Error solución analítica 12.97 m | Error modelo ML 8.01 m | para el RP131

— Simulación
— Modelo ML
• Dato medido

» what are the next steps?

- Neural Hierarchical Interpolation for Time Series (NHITS)



- Coupling numerical simulations to be refined by ML model

»» Some conclusions at this stage

- ❑ The results obtained have shown that machine learning approaches:
 - Present satisfactory predictive capacity
 - They can be quick and effective tools in making decisions about the impacts of production wells during development of open pit mine dewatering
 - Can be applied as support in the planning for the water operations in the pit.

- ❑ There is a need of having a big amount of data, and ‘as good as possible’...
... Taking care with this! ML can increase the speed of interpretation but may lead to poorer outcome
- ❑ Some dewatering methodologies (e.g. drains in the wet walls of the pit) can hardly be reproduced
- ❑ Same than with numerical models, it is fully recommended that the ML-based hybrid model be developed with the site knowledge and singularities, it is crucial to reflect geology features within the assignment of hydraulic properties, a set of piezometric data and pumping information, that is sufficiently extensive well validated by water specialists with historical knowledge on the pit

» A final thought



Let us use both **intelligences**

on the one hand, the **human** one, in which we integrate all the knowledge of the specialists involved: mining engineers and geologists, geotechnical engineers and groundwater specialists to recognise and accommodate water-related factors

on the other hand, the **artificial** one, which will allow us to extract and integrate complex patterns in the management of large volumes of information, with an astonishing speed for predictions.

Thanks a lot for your attention!

The authors would like to thank Antamina for the years of work in the development of hydrogeological and dewatering activities, for the search for innovative solutions that allow more agile and accurate decisions to be made, and for the presentation of these results.

questions / comments

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references

