Seamlessly Integrated Modelling Approach: From Conceptual Geological to Numerical Models

Mundzir Basri, Stantec, Canada
Miad Jarrahi, Stantec, Canada
Pramod Pokharel, Stantec, Canada
Estefany Tisza, Stantec, UK
Bernard Ayumu, Stantec, Canada

Abstract

Three-dimensional conceptual geological models (CGMs) of complex hydrogeological systems are often simplified in numerical groundwater models to analyze groundwater flow regimes. Although CGMs are accurately developed in most cases, the oversimplification of critical geological features in numerical models do not reflect CGMs to simulate the groundwater flow system. This leads to simulated results often not comparing well with observed data. The objective of this study is to address this problem through a seamlessly integrated modeling approach that retains key geological / hydrogeological features from CGMs in numerical groundwater models. This eliminates the disconnect between CGMs and numerical groundwater flow models. This paper applied the approach in the development of a groundwater flow model for a mine site. The three-dimensional CGM was developed in Leapfrog Works and integrated into FEFLOW using Leapfrog's hydrogeology module as an input file. Results from the numerical groundwater flow model showed no reduction of geological features from the CGM. Simulated well data also closely matched observed well data; hence highlighting the success of this approach in improving the groundwater modelling process.

Introduction

An understanding of geology is fundamental to numerical groundwater modeling. Hydraulic heads, flow directions, residence times, and other hydrogeological properties are strongly controlled by geological features. Therefore, an accurate conceptualization of geological models is a fundamental and crucial step for understanding geological controls on groundwater hydrodynamics.

Conceptual geological modelling involves the analysis and 3D visualization of geological data and geological information collected from borehole logs, geological maps, geophysical data, and basin analysis. These conceptual geological models (CGMs) often provide information about geological processes, rock type, age, thickness, discontinuities like folds, faults, and other petrophysical properties such as porosity and permeability. Groundwater numerical models, on the other hand, provide information about groundwater flow directions, flow velocity, travel time, permeability, storativity, dispersivity, concentration, initial and boundary conditions, etc., all of which are dependent on CGMs. The development of a numerical model involves the discretization of the model domain using Finite Differences Method (FDM) or Finite Element Method (FEM). These FDM or FEM packages then use numerical codes to solve the groundwater flow equations with respect to time.

Significant advancement in computing technology in recent years has made the complex tasks of geological modelling and groundwater modelling less cumbersome through the development of robust modelling tools like Leapfrog Works (Seequent 2017) and FEFLOW (DHI 2022). These have helped in narrowing the gap that exists between geological modellers and groundwater modellers who often work independently and for different objectives. For example, whereas geological modellers place strong emphasis on rocks (stratigraphy) and geological processes, groundwater modellers are more focused on groundwater flow mechanisms and aquifer parameters resulting in huge gaps between these two fields. Apart from this huge gap, frequent simplifications of critical geological features in numerical groundwater models may impact actual flow systems. This means that the performance of a particular numerical groundwater model solely depends on the initial subjective discretion of the modeller.

This paper addresses the disconnect between CGMs and numerical groundwater models through a seamless integrated modelling approach that retains key geological features from CGMs for effective numerical groundwater modelling. This integrated modelling approach is not a substitute for superior quality field data that is always required for the development of CGMs nor is it an automatic guarantee for good numerical groundwater results. It only serves to limit the often-oversimplified assumptions regarding geological features in numerical groundwater modelling.

Methodology

The study commenced with the development of simple CGMs and numerical groundwater models using Leapfrog Works (Seequent 2017) and FEFLOW (DHI 2022) respectively.

Leapfrog uses data and parameters such as lithological codes, Digital Elevation Models (DEMs) and drawn

polylines, to implicitly construct surfaces based on spatial interpolation of the point attributes using radial basis functions (RBF), and kriging techniques to construct CGMs (Seequent 2017).
FEFLOW on the other hand, discretizes the model domain using the Finite Element Method (FEM) to solve the groundwater flow equations using built-in numerical codes.

Data and discussion

Different CGMs were first developed for simple geological formations before applying the integrated modelling approach to a more complex geology. Conceptual geological models were developed from stratigraphic data obtained from borehole logs, mapped fault lines, and fractures. These geological data and information were compiled, modelled, and visualized with Leapfrog Works. The left side of Figure 1 shows a simple CGM developed with Leapfrog Works. From the same data, several other simple CGMs depicting different geological scenarios (not shown here) were also developed. These included cases of simple formations with vertical faults and no shifted stratigraphy as well as cases with inclined faults with no shifted stratigraphy. In all the geological scenarios, the Leapfrog model's interpretation of field data closely matched what the geologist had conceptualized. With Leapfrog's hydrogeology module as an input file, the CGM developed for each geological scenario was integrated into FEFLOW seamlessly while retaining the integrity of these geological features. An example of such seamless integration is shown in Figure 1. This integrated modelling approach was then applied to a more complex geological formation (mine site) after its success on simple cases. The site data included long records of observed data from hundreds of wells, stratigraphic data depicting different geological formations, hydrological data, and hydrogeological data. The shallow well data depicted the hydrogeological conditions of the upper alluvial aquifer while the deeper well data described the conditions of the weathered and fresh bedrocks. The vertically declined hydraulic conductivity of the bedrock was implemented in the model. After the interpretation of field data by the developed Leapfrog CGM had closely matched what the geologists had conceptualized for the site, the CGM was then seamlessly integrated into FEFLOW. In FEFLOW, two groundwater flow modelling scenarios were implemented. The first was based on the retained geological features from Leapfrog's CGM while the second scenario was based on the case where geological details of the mine site were modified according to the groundwater modeller's discretion. For instance, multilayered alluvial sediments were assumed to be a single material and assigned a single hydraulic conductivity value. Similarly, the bedrock was assumed to be impermeable and assigned a lower hydraulic conductivity instead of assigning higher hydraulic conductivity values for the weathered and fractured parts. Results from these two scenarios were later compared.

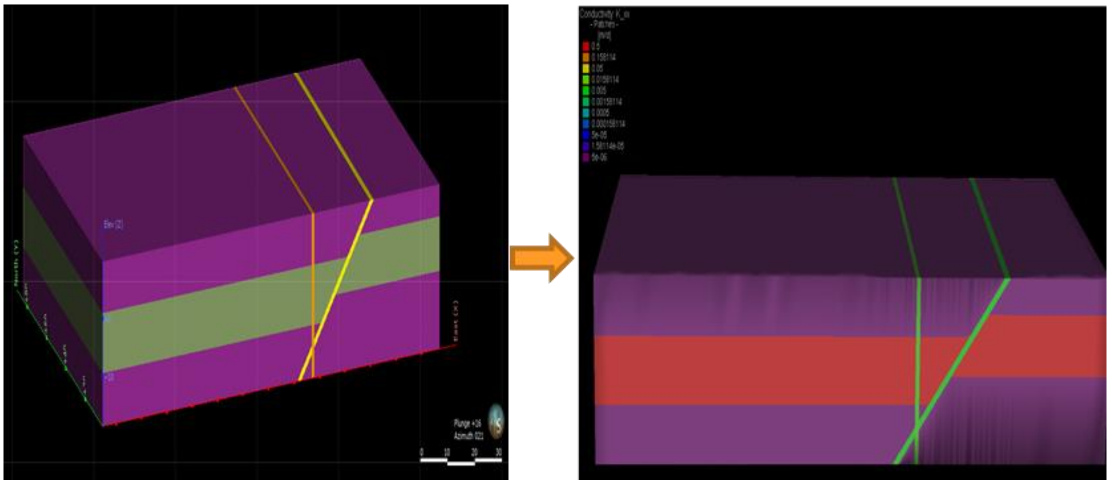

Figure 1: Conceptual Geological Model developed in Leapfrog Works (left) integrated seamlessly into a numerical groundwater model (right) using Leapfrog's hydrogeology module

Results

After applying the integrated modelling approach to the developed Leapfrog CGM of the mine site (Figure 2), features such as layered alluvial deposits, and deep highly fractured and faulted zones around ore bodies, that would have usually been oversimplified in most groundwater models were retained in the FEFLOW model. Similarly, pinching layers and bedding layers were retained in the numerical FEFLOW model without any simplifications or modifications (Figure 3).

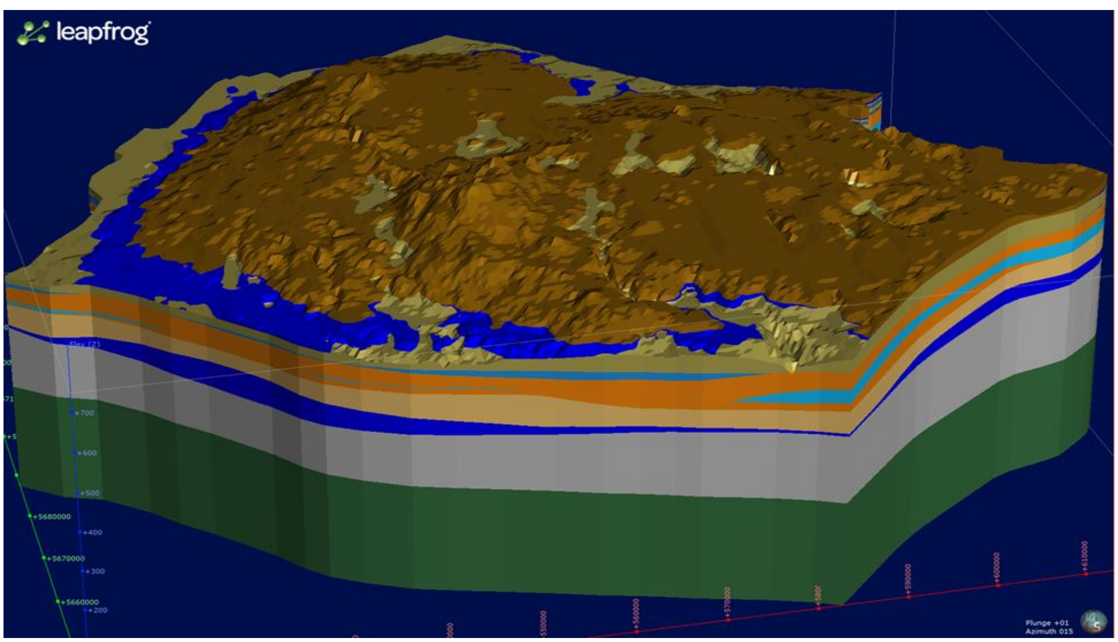

Figure 2: Three-dimensional representation of the conceptual geological model (CGM) of Mine Site

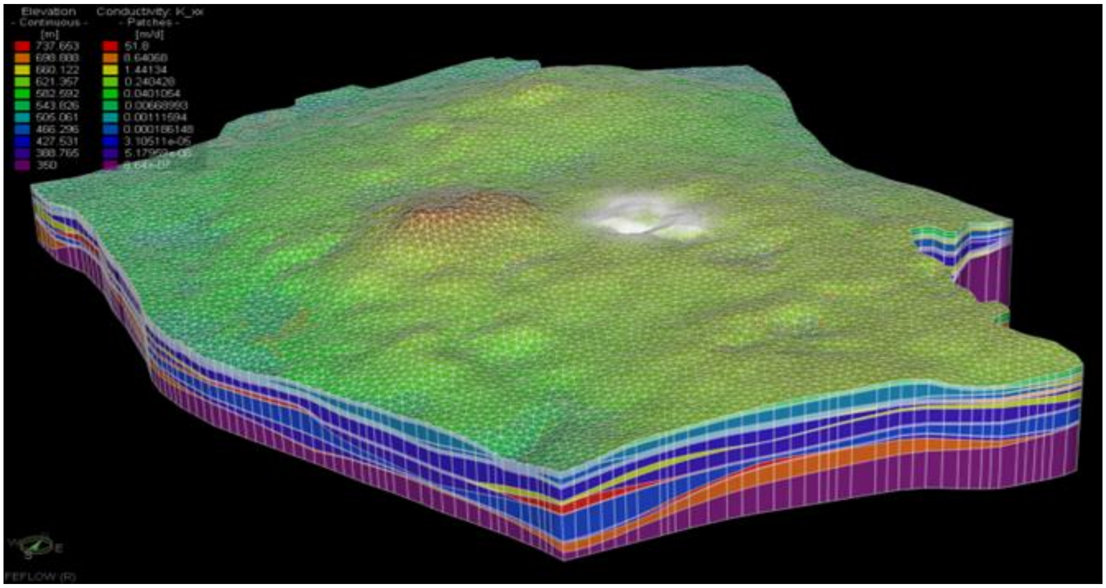

Figure 3: Geometry of the 3-D finite element groundwater flow model seamlessly transferred from the CGM in Figure 2

The two numerical FEFLOW groundwater modelling scenarios tested on the mine site provided different results. The model calibration performed in the scenario with averaged stratigraphic units, smoothed pinching layer, and other modifications made to geological features on the site resulted in simulated groundwater results not matching well with observed data (Figure 4).

The other scenario which, however, involved a seamless integration of the CGM from Leapfrog Works into the numerical FEFLOW model showed a good match between simulated and observed data after the model calibration (Figure 5). Although the authors agree that no model is perfect in terms of matching exactly real-world values, the integrated modelling approach however, provided good estimates of groundwater inflows than the case that incorporated modifications to geological features on the site.

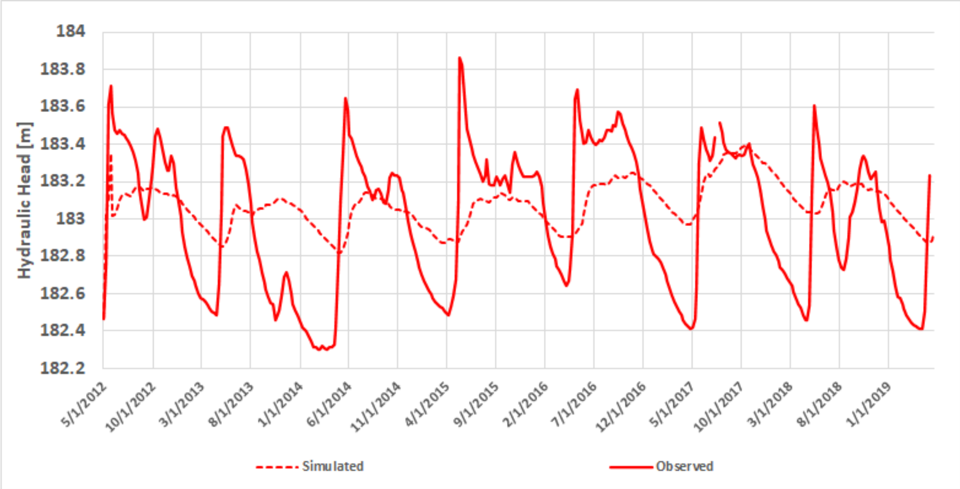

Figure 4: Simulated vs observed data for one of the groundwater monitoring wells from FEFLOW numerical modelling on the simplified assumption of homogeneity for a layered system

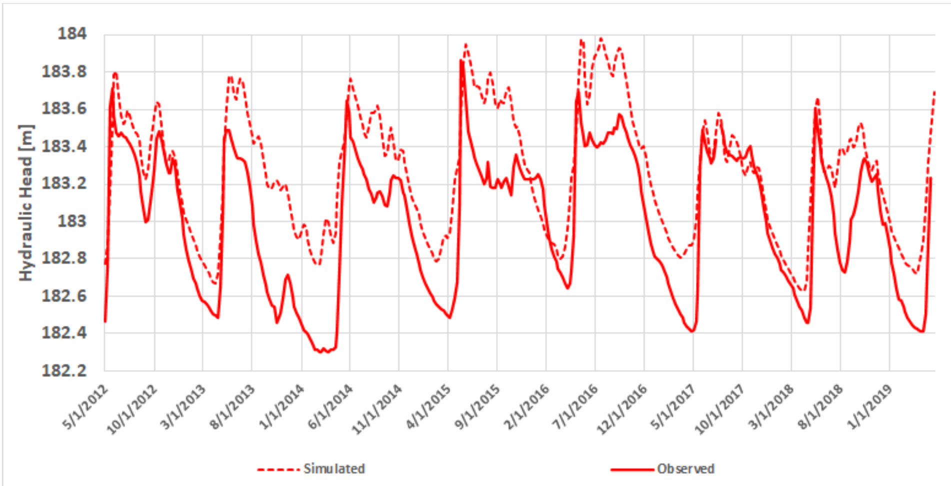

Figure 5: Simulated vs observed data for one of the groundwater monitoring wells from the numerical FEFLOW modelling after a seamless integration from the CGM

Conclusion

Developed numerical groundwater models often incorporate many modifications or simplifications of geological features that do not closely match their corresponding CGMs. This often results in simulated groundwater data not comparing well with observed real-world data. This study investigated a seamless integrated modelling approach from a Leapfrog Works CGM into a numerical FEFLOW groundwater model as a means of addressing the problem of oversimplification of geological features in groundwater models. Application of this approach to the development of a groundwater flow model for a mine site indicated that geological features in the CGM are not only retained in the numerical model but also improve the groundwater modelling process by producing results which closely match observed data. This was confirmed by two FEFLOW groundwater modelling scenarios where the seamless integrated modelling approach produced better results than the case where geological modifications were incorporated in the modelled site.

References

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