How Much Is Enough? Developing an International Standard of Reporting for Mine Water Hydrogeology

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Abstract

International guidelines exist for reporting of mineral resources (SAMREC, JORC), (engineering and hydro-) geological investigations (ASTM, British Standard) and environmental geochemical characterisation (GARD). Yet, mining hydrogeological investigations have been neglected in this regard, relying on varying district governmental guidelines. This study reviews and analyses existing guidelines to produce standardised guidelines similar to ASTM or JORC. However, this is the first step to conflating international practices to compile an internationally accepted reporting benchmark. This research explores fundamental principles of groundwater movement and hydrogeological influences on a mining site, identifying appropriate characterisation methods and data resolutions required for various levels of characterisation.

Keywords: reporting standard, quantified benchmark, mine water, hydrogeological investigation

Introduction

Reporting guidelines for mining related hydrogeological studies vary widely based on geographical setting (Barnett et al. 2012; EBRD 2014; EPA 1994; ICMM 2017; IFC 2007; IFC 2007; JORC 2012; NI43-101; Stephenson 2000). Often these guidelines are based on a national or international understanding and approach to investigation. However, the requirements are often subjective and unquantifiable. This results in a variable benchmark in justification of the use of specific methods to perform investigations. Further to this is the absence of technical guides providing methods to quantify e.g. representative sample numbers and test numbers per investigation. Therefore, subjective judgement of the validity of mining hydrogeological studies is possible if a universal quantitative guideline does not apply. An example of the elimination of this bias is the JORC standard of mineral resource reporting where quantified approaches are followed to determine a resource/reserve estimation with various levels of certainty which are internationally accepted. The development of quantified benchmarks for reporting is imperative if mine water challenges are to be addressed effectively and co-operatively.

Methods

Comparisons of various guidelines for the reporting of hydrogeological parameters and investigations was performed to identify any possible quantitative guides (Barnett et al. 2012; EBRD 2014; EPA 1994; ICMM 2017; IFC 2007; IFC 2007). However, none of these documents provide a quantifiable level for data compliance and rely on expert judgement. In contrast, the methods articulated in JORC contain clear definitions on the quantification of resources/reserves. Since its implementation, substantially improved standards of public reporting have prevailed in mining throughout Australasia (Stephenson 2000). This can largely be attributed to consensus on standards between mining companies, quantitative standards and the code being a requirement for listing on the Australian Stock Exchange. Therefore, the identification of a method to quantify a reporting standard for data as well as interpretation confidence in mining- related hydrogeology was deemed necessary. Mining assets (resources/reserves) can only be quantified realistically by also accounting for quantified liabilities with water management and control being a critical expenditure during operations. However, the complexity of hydrogeological systems must be realistically represented spatially and temporally to define reliable water management goals.

Spatial parameter variability and the quantification of its effect on natural systems is the focus of many natural scientific studies. However, without fixed, measured parameters this can seem like an impossible task. Furthermore, the representation of a natural system by a subset of samples is generally a limiting factor in the accuracy of calculations with regards to that system. However, by applying a "theory of constraints" (Goldratt 2016) combined with statistical analysis of available data the quantification of a hydrogeological system's behaviour becomes increasingly reliable. The application of the theory of constraints and the associated statistical analyses are discussed in the sections below.

Results and Discussion

Delineating the Area of Influence/Main Constraint

Delineation of this main constraint is no stranger to numerical flow modellers of both surface - and groundwater. However, topography, surface drainage and mining depths provide some clues to the delineation of the aquifers influenced by mine depressurisation. In a fractured rock aquifer, groundwater levels often emulate topography. Therefore, a conceptual understanding of the three-dimensional distribution of groundwater heads and transfer of groundwater between aquifers can be developed. To simplify, the main constraint on the quantification of the hydrogeological system is the identification of a system domain (Diersch 2013). This boundary must follow zero-flow and constant head boundaries which are as near as possible to the maximum extent of potential steady-state mine depressurisation without influencing calculation results and including all potentially affected water sources (Barnett et al. 2012).

Sub-Constraints within the Main Constraint

Selecting the hydrogeological domain fixes the spatial variability of hydraulic parameters to a certain degree in terms of sources, sinks and fluxes. Although temporal variability is not fixed within the main constraint, temporal variables can be measured much more accurately and representatively e.g. rainfall, streamflow, groundwater abstraction etc. These variables act as sub-constraints of mathematically describing the hydrogeological system. Similarly, aquifer hydraulic properties e.g. transmissivity, porosity, specific storage etc. (another sub-constraint) may remain fixed but are spatially variable. The quantification of this variability is considerably more challenging with limited resources and the identification of boundaries to a representative elemental volume may become impossible. However, defining a sub-constraint requires multiple properties for its delineation. In a hydrogeological system, the main focus of a spatial sub-constraint definition is geometry of physical attributes. An example would be the delineation of the geometric extent of a specific lithology with a specific hydraulic conductivity, porosity and storativity. This approach also applies to structural discontinuities and would include spatial orientation.

Selection of Sample Size to Represent Sub-Constraint Properties

A sub-constraint therefore represents a population with a specific set of attributes. Several testing methods are used to determine e.g. the hydraulic properties of an aquifer. However, the spatial extent of these tests are only representative of a portion of the sub-constraint population i.e. the aquifer. Unfortunately, no guideline currently addresses how representative a dataset should be in a quantitative manner. Therefore, sample numbers are left to the subjective discretion of the scientist. To eliminate bias from this method statistical methods of sample size selection are proposed e.g. Cochran's formula. This provides a quantitative confidence level to the selection of statistical sample numbers to describe a population in a representative way (Field 2013). An example of sub-constraint sample size determination would be a specific lithology on-site with specific hydraulic parameters unique to that lithology. Therefore, a number of hydraulic tests may need to be performed on that lithological unit to representatively quantify its hydraulic parameters.

Extrapolation of Sub-Constraint Properties

Once the sub-constraints of the hydrogeological system have been identified and representatively quantified in a statistically sound dataset, extrapolation of these properties throughout the main constraint domain is possible, per sub-constraint. Because a representative dataset of each sub-constraint population exists, various interpolation methods can be tested against the dataset to best represent the sub-constraint spatial variability (Reilly and Harbaugh 2004). This eliminates subjective selection of interpolation methods to represent sub-constraint populations.

Quantification of the Hydrogeological System

A representative set of fixed spatial sub-constraints and potentially variable temporal sub-constraints can now be incorporated into the calculation of a hydrogeological system's behaviour with an associated confidence level. A subsequent result of applying this method is the reduction in potential stochastic realisations which could describe a calibrated system and a more realistic representation of system dynamics. Numerical flow modelling is currently the best available tool for the calculation of groundwater flow in various scenarios. However, a model is only accurate and representative to the level of confidence of its input data (Diersch 2013). Statistically representative sampling of sub-constraints in a hydrogeological system provides a quantitative method of demonstrating model reliability.

Changes in Sub-Constraints – System Behaviour Re-Quantification

As mentioned, the spatial variables in a hydrogeological system are often fixed and challenging to quantify on a large scale while temporal variables are often easily measured and quantified. However, some of these variables e.g. hydraulic conductivity, can change from a spatial variable to a temporal variable. This applies especially in mining environments where excavation and dewatering of a mine substantially changes the localised hydraulic properties of an aquifer, turning a lithological mass into a free draining void. The implication of this an increase in reliability of calculation as a statistically represented value turns into a certain and measured value. Introduction of this additional constraint therefore has a positive effect on quantification as subjectiveness and data uncertainty are reduced. This implies that confidence in the calculation of system behaviour can now further be quantified rather than judged subjectively.

Conclusions

Although various guidelines and standards exist for the approach to performing a hydrogeological investigation at a mining site none provide a fixed reference point. Variation in methodologies between countries, jurisdictions and scientific communities have left this task subjective and its approaches qualitative based on circumstantial evidence. A unified, measurable standard is needed for evaluation even if a degree of freedom in terms of methods is retained. Therefore, a quantifiable benchmark in terms of characterisation would serve to eliminate bias and provide an invariable standard of evaluation, regardless of geographical location or approach. Identifying the constraining factors for the quantification of natural systems with regards to spatial and temporal variables and quantifying the confidence of representations will not only improve scientific understanding but the international standard of reporting quality. Integration of system constraints, statistics and science is fundamental to representativeness and transparency in mine water hydrogeological investigations and imperative for advancement as a unified scientific community.

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