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Inverse problems in engineering

Llopis-Albert, Carlos[a]; Palacios-Marques, Daniel[b]

[a] Departamento de Ingeniería Mecánica y de Materiales, Universitat Politècnica de València, Camí de Vera s/n, Spain, 46022, email: cllopisa@upvnet.upv.es

[b] Departamento de Organización de Empresas, Universitat Politècnica de València, Camí de Vera s/n, Spain, 46022, email: dapamar@doe.upv.es

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Abstract

An inverse problem in engineering is the process of obtaining from a set of observations the causal factors that produce those data. Contrary to forward problems, an inverse problem starts with the results and subsequently calculates the causes. They are widely applied in many engineering fields since they allows obtaining parameters that cannot be directly observed. Additionally, they play a major role in uncertainty, reliability and risk assessment. This paper discusses an uncertainty assessment about the environmental impacts of future scenarios of sustainable groundwater pumping strategies on the quantitative status of an aquifer.

Keywords: Inverse problems, water resources management, uncertainty assessment, stakeholders, decision-making

1. Introduction

Sustainable water resources management is becoming more critical because of the rising pressure of global water shortage and climate change. This is also hampered by the uncertainty regarding groundwater parameters and future water demands, together with the existence of stakeholders with conflicting interests. Groundwater management entails situations such as pumping strategies to sustain irrigated crops and to supply groundwater to the urban and industrial sectors. The decision-making process to define the best management practices and strategies needs a good understanding about the groundwater parameters of an aquifer. For that, a stochastic inverse model named GC method (Llopis-Albert 2008; Capilla and Llopis-Albert, 2009) is applied to the Jumilla-Villena aquifer, which is located in SE Spain. It calibrates equally likely realizations of hydraulic conductivity (*K*) fields conditional to hard data (*K* and piezometric head data, *h*) and soft data (geophysical information and expert knowledge), while considering the physical processes taking place at the aquifer.

After the conditioning process, a set of simulated future scenarios of groundwater pumping strategies is applied to each one of the calibrated *K* fields, which leads to divergent environmental impacts, levels of socio-economic development for the area and a diverse degree of acceptance among stakeholders. In this way, the uncertainty assessment is carried out by means of MonteCarlo simulations and to determine if the water system meets the EU Water Framework Directive (WFD) standards (EC, 2000).

2. Material and methods

2.1. Inverse model

The GC method is a stochastic inverse modelling technique for the simulation of conductivity (*K*) fields (Llopis-Albert, 2008; Capilla and Llopis-Albert, 2009; Llopis-Albert and Capilla, 2009; Llopis-Albert and Capilla, 2009a; Llopis-Albert and Capilla, 2010; Llopis-Albert and Capilla, 2010a; Llopis-Albert et al., 2014; 2015; 2016. The method is based on the gradual deformation technique (Hu, 2000). It entails an iterative optimization procedure for constraining stochastic simulations to flow and mass transport information. The iterative procedure implies non-linear combinations of seed *K* fields (already conditional to *K* data an soft information such as expert judgment and geophysical surveys) with the conditional *K* field of a previous iteration. The combined *K* field preserves the mean, variance, variogram and data conditioning when the linear combination coefficients meet several constraints. Finally, the iterative procedure requires minimizing an objective function that penalizes the difference between computed and measured conditioning data. Following this procedure an ensemble of a hundred calibrated *K* fields were obtained, in which the future pumping scenarios were simulated using the code MODFLOW (McDonald and Harbaugh 1988; Harbaugh et al. 2000).

2.2. Case study

The Jumilla-Villena aquifer (SE Spain) has a surface of over 338 km^2 and the water reserves are estimated in 1400 hm^3. A negative piezometric level trend is recorded since the begging of abstractions, which has led to officially declare the aquifer as an over-exploited in 1987. Consequently the abstractions are limited, irrigated surface cannot be larger and User's Communities are established as a control mechanism. For the time period from 1985 to 2004 the annual abstractions are around 42.7 hm^3/year and the recharge is estimated in 7.5 hm^3/year. Overall the aquifer presents a water balance disequilibrium of about 35 hm^3/year. The model domain is made up of 79 columns, 26 rows, and 1 layer, with a total of 2054 (but only 1352 cells are considered as active cells) square cells of 500 m^2, i.e., 13 x 39.5 km. An unconfined aquifer with no flow boundary conditions is used. The temporal discretization spans from 1985 to 2004 with monthly time steps.

There are 73 pumping wells and 59 head observation boreholes spatially distributed all over the aquifer. The calibration of the flow model was performed using historical data, which encompasses *K*, *h*, pumping rates, recharge, pumping tests and expert judgment (CHS 2016; CHJ, 2016). A sequential indicator simulation was used to generate the seed *K* fields.

Four future scenarios (*S*) regarding pumping strategies were simulated based on available information (CHS, 2016; CHJ, 2016). They lead to different environmental impacts, levels of socio-economic development for the area and degree of acceptance among stakeholders. *S1* is the business as usual scenario (i.e., current rate of exploitations will be used in the future). *S2* makes use of external water resources to decrease the water pressure (e.g., water transfers from other river basins). *S3* is the scenario with more water demanding. *S4* reduces the irrigated areas by gradual acquisition of water rights (applied on crop areas of lower productivity). *S4* entails more abstractions than *S2* but less than *S3*.

These four scenarios were simulated on the 100 calibrated *K* fields in order to obtain the groundwater levels and drawdowns in the aquifer. The calibration procedure reduces the disagreement between measured and simulated data. The final goal is to determine if the water system will achieve the good quantitative groundwater status as established by the WFD.

3. Results and discussion

The inverse model allows determining the groundwater levels for the calibrated *K* realizations and the 4 scenarios at each specific observation well. Results show a good agreement between observed and simulated values is achieved. *S1* and *S2* lead to a slight recovery of the groundwater levels. Contrary, *S3* and *S4* entail a continuous declining of groundwater levels. These declines have different slopes because of the intensity of the future pumping strategies. Similar declines in groundwater levels are observed for all the observation wells.

Results show that the current abstractions can be maintained until the year 2025, but with a gradual increase of the energy cost of pumping because of the need of making deeper wells or change their spatial location.

Results also show that the recovery of the aquifer to the levels prior to the beginning of abstractions cannot be achieved.

In addition, this entails that quality problems such as the water salinity or the purpose of keeping the nitrate concentrations within the target levels, as defined by the WFD, might worsen. The MonteCarlo simulation technique was applied using the 100 calibrated *K* fields, wich allows assessing the uncertainty regarding the groundwater levels. Again, results show for all calibrated *K* fields that a good fit between the calculated and observed head values is obtained. Results also show that the water levels continue decreasing for all *K* fields, and a significant variance of more than 30 m between them for a specific time. This proves the worth of using stochastic inverse models in environmental projects.

4. Conclusions

The use of inverse models in environmental projects allows assessing the uncertainty. Therefore, it can help in the decision-making process in the presence of stakeholders with conflicting interest. This has been proven in a real case study by calibrating a groundwater flow model using the GC method, which takes into account the physical behavior of the water system. Furthermore, different policies regarding pumping strategies have been simulated, which allows determining if the WFD standards are met.

References

Capilla, J. E., Llopis-Albert, C. (2009). Gradual Conditioning of Non-Gaussian Transmissivity Fields to Flow and Mass Transport Data. Journal of Hydrology, 371, 66-74. doi: 10.1016/j.jhydrol.2009.03.015.

CHJ (Júcar Water Agency) (2016). Júcar river basin authority. http://www.chj.es/

CHS (Segura Water Agency) (2016). Segura river basin authority. http://www.chsegura.es/

EC (2000). Directive 2000/60/EC of the European Parliament and of the Council of October 23 2000 Establishing a Framework for Community Action in the Field of Water Policy. Official Journal of the European Communities, L327/1eL327/72. 22.12.2000.

Harbaugh, A.W., Banta, E.R., Hill, M.C. and McDonald, M.G. (2000). MODFLOW- 2000, The U.S. Geological Survey modular groundwater model-User guide to modularization concepts and the groundwater flow process. US Geol. Surv. Open-File Rep 00–92, 12.

Hu, L.Y. (2000). Gradual deformation and iterative calibration of Gaussian related stochastic models. Mathematical Geology, 32 (1), 87–108.

Llopis-Albert, C. (2008). Stochastic inverse modeling conditional to flow, mass transport and secondary information. Edited by Universitat Politècnica de València (Spain). ISBN: 978-84-691-9796-7.

Llopis-Albert, C. and Capilla, J.E. (2009). Gradual Conditioning of Non-Gaussian Transmissivity Fields to Flow and Mass Transport Data. Demonstration on a

Synthetic Aquifer. Journal of Hydrology, 371, 53-55. doi: 10.1016/j.jhydrol.2009.03.014.

Llopis-Albert, C. and Capilla, J.E., (2009a). Gradual Conditioning of Non-Gaussian Transmissivity Fields to Flow and Mass Transport Data. Application to the Macrodispersion Experiment (MADE-2) site, on Columbus Air Force Base in Mississippi (USA). Journal of Hydrology, 371, 75-84. doi: 10.1016/j.jhydrol.2009.03.016.

Llopis-Albert, C. and Capilla, J.E., 2010. Stochastic simulation of non-Gaussian 3D conductivity fields in a fractured medium with multiple statistical populations: a case study. Journal of Hydrologic Engineering, 15(7), 554-566. doi: 10.1061/(ASCE)HE.1943-5584.0000214.

Llopis-Albert, C. and Capilla, J.E. (2010a). Stochastic inverse modeling of hydraulic conductivity fields taking into account independent stochastic structures: A 3D case study. Journal of Hydrology, 391, 277–288. doi: 10.1016/j.jhydrol.2010.07.028.

Llopis-Albert, C., Palacios-Marqués, D., Merigó, J.M. (2014). A coupled stochastic inverse-management framework for dealing with nonpoint agriculture pollution under groundwater parameter uncertainty. Journal of Hydrology 511, 10–16. doi: 10.1016/j.jhydrol.2014.01.021.

Llopis-Albert, C., Pulido-Velazquez, D. (2014). Discussion about the validity of sharp-interface models to deal with seawater intrusion in coastal aquifers. Hydrological Processes 28(10), 3642–3654.

Llopis-Albert, C., Pulido-Velazquez, D. (2015). Using MODFLOW code to approach transient hydraulic head with a sharp-interface solution. Hydrological Processes 29(8), 2052-2064. doi: 10.1002/hyp.10354.

Llopis-Albert, C., Merigó, J.M, Palacios-Marqués, D. (2015). Structure Adaptation in Stochastic Inverse Methods for Integrating Information. Water Resources Management 29(1), 95-107. doi:10.1007/s11269-014-0829-2.

Llopis-Albert, C., Merigó, J.M., Xu, Y. (2016). A coupled stochastic inverse/sharp interface seawater intrusion approach for coastal aquifers under groundwater parameter uncertainty. Journal of Hydrology 540, 774–783. doi:10.1016/j.jhydrol.2016.06.065.

McDonald, M. G., & Harbaugh, A. W. (1988). A modular three-dimensional finite-difference groundwater flow model. US Geological Survey Technical Manual of Water Resources Investigation, Book 6, US Geological Survey, Reston, Virginia, 586.