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Decision-making and stakeholders' constructive participation in environmental projects☆

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ABSTRACT

Integrated water resources management means making decisions and taking actions while focusing on how managing water. This study identifies the stakeholders participating in decision-making process of Jumilla-Villena aquifer (SE Spain), their objectives, and alternative actions that stakeholders should consider in the public participation project. If the system achieves the good quantitative groundwater status in the context of the EU Water Framework Directive (WFD), future scenarios regarding pumping strategies may arise. These future scenarios will lead to different environmental impacts and socio-economic development of the region, and hence, to a different acceptance degree between stakeholders. This study establishes the foundations to perform a public participation project and contributes to define the best management policies for the groundwater system.

1. Introduction

Integrated water resources management involves technical, scientific, political, legislative, and organizational aspects of water system. Water resources management suffers from continual and growing pressures (Perez-Pineda & Quintanilla-Armijo, 2013). These pressures on water resources derive from reasons such as human activity, population growth, living standards increase, land-use and climate changes, growing competition for water, and pollution from industrial, municipal, and agricultural sources. The WCED (1987) define sustainability according to these reasons.

Aquifer over-exploitation may lead to water level drawdown (i.e., abstraction cost increase), progressive water quality deterioration (e.g., soil salinization), ecological damage (e.g., rivers and springs flow decrease), and subsidence and landslide processes (Bacchus, 2000). The EU Water Framework Directive (WFD) requires member states to “protect, enhance and restore all bodies of groundwater” to reach a good (quantitative and chemical) groundwater status by 2015 (EC, 2000). The Groundwater Directive (GWD) encourages the identification and disposal of any significant pollutant concentration (EC, 2006).

The WFD also recognizes economics' role in reaching the environmental and ecological objectives. Won-Suk, Dong-Eun, and Jae-ho (2014) indicate the necessary balance between environmental damage costs (which are not readily assessable) and water benefits of the water for region's sustainable socio-economic development. Different policy instruments for groundwater management can cope with present and future situations (water pricing, quotas, water abstraction taxes, pollution taxes, subsidies, tradable permits, or groundwater banking). The final goal is to combine existing regulations, institutional capability, social acceptability, stakeholder involvement, and political will.

However, because of the complexity of interactions between economic, agronomic and hydrologic systems, the stochastic nature of some factors (e.g. climate, soil, topographic conditions, etc.), and to the lack of knowledge, the consequences of management practices recommended by the authorities are difficult to predict accurately. Despite these facts, numerical simulation models—which may explicitly take into account the biophysics of the aquifer, and integrate its socio-economic characterization—can help in both the decision-making process and the uncertainty assessment.

The Jumilla-Villena aquifer (SE Spain), officially over-exploited, provides the scenario for this study. A calibrated groundwater flow model (which considers physical processes in the aquifer) generates different scenarios regarding future pumping strategies. These scenarios will show different environmental impacts and region's socio-economic development, and hence, a different degree of acceptance by stakeholders. This study identifies the stakeholders, the objectives according to the WFD, and the alternative actions to take into consideration in a public participation project. This study establishes the foundations to perform a public participation project and contributes to define the best management policies for the groundwater system. Furthermore, a

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Table 1
Historical data of water demand, uses for the groundwater abstractions, and annual water balance of the aquifer.

Agricultural water demand (Mm^3/year)			Abstractions for irrigation (Mm^3/year)			Abstractions for domestic water (Mm^3/year)			Other uses (Mm^3/year)	Total uses (Mm^3/year)		
Segura Basin	Júcar Basin	Total	Segura Basin	Júcar Basin	Total	Segura Basin	Júcar Basin	Total	Total	Segura Basin	Júcar Basin	Total
28	17	45	21	17 —	38	1	6	7	0.7	22	24	46

Recharge (Mm^3/year)	Actual pumping (Mm^3/year)	Storage variation (Mm^3/year)	Total drawdown since natural regime (m)	Water table depletion rate during the last 10 years (m/year)
7.5	42.7	−35	115	3.5

comparison may arise between economical and environmental groundwater costs and other water sources such as desalinization plants, conjunctive use of groundwater and surface water, or water transfer between river basins.

2. Modeling framework

This study uses MODFLOW to simulate groundwater flow in the aquifer (McDonald & Harbaugh, 1988). This method solves the flow equation in three dimensions using an approximation by finite differences and a constant density. Nonlinear parameter estimation can calibrate the hydrogeological parameters of the equation (Llopis-Albert & Capilla, 2010a, 2010b; Llopis-Albert, Palacios-Marqués, & Merigó, 2014). This study uses an automatic calibration through PEST parameter estimation model (Doherty, 2004). This automatic calibration adjusts model input data and runs the model again until achieving a specific number of optimization iterations or a convergence criterion. High computational efficiency is necessary for the calibration process due to the implementation of the parameter estimation algorithm (Gauss–Marquardt–Levenberg algorithm). This algorithm has its basis on an iterative process implying a linearization of the relationship between model parameters and model-generated observations through a Taylor expansion of the best parameter set. This algorithm obtains all observations derivatives regarding all parameters. After solving the problem, a better parameter set appears. Therefore, the problem is to minimize the following objective function (ϕ):

$$\phi = (\mathbf{c} - \mathbf{c}_o - \mathbf{J}(\mathbf{b} - \mathbf{b}_o))^t \mathbf{Q}(\mathbf{c} - \mathbf{c}_o - \mathbf{J}(\mathbf{b} - \mathbf{b}_o)) \tag{1}$$

where: $\mathbf{c}$: Experimental observation vector; $\mathbf{c}_o$: Model-calculated observation vector; $\mathbf{J}$: Jacobian matrix. J_{ij} is the derivative of the piezometric function of the i'th observation with respect to the j'th parameter; $\mathbf{Q}$: Observation weights matrix (square and diagonal) whose i'th diagonal element q_{ii} is the square of the weight w_i attached to the i'th observation; $\mathbf{b}$: New parameter vector; $\mathbf{b}_o$: Current parameter vector; $\mathbf{u} = (\mathbf{b} - \mathbf{b}_o)$: Parameter upgrade vector.

Applying Taylor's theorem,

$$\mathbf{c} = \mathbf{c}_o + \mathbf{J}(\mathbf{b} - \mathbf{b}_o) \tag{2}$$

and the upgrade vector $\mathbf{u}$ becomes,

$$\mathbf{u} = \left(\mathbf{J}^t \mathbf{Q} \mathbf{J}\right)^{-1} \mathbf{J}^t \mathbf{Q}(\mathbf{c} - \mathbf{c}_o) \tag{3}$$

Finally, the parameter covariance matrix is:

$$C(\mathbf{b}) = \sigma^2 \left(\mathbf{J}^t \mathbf{Q} \mathbf{J}\right)^{-1} \tag{4}$$

where σ^2 represents the variance of each of the elements of $\mathbf{c}$.

3. Methodology

Aquifer over-exploitation is an important part of the agricultural and economic development in Spain. Moreover, summers' higher population due to tourism increases water demand, which aquifers extractions satisfy. This intensive exploitation of aquifers causes severe political conflicts between local towns, districts, regional governments, and with national government. Furthermore, this intensive exploitation strongly affects ecology: From springs and wetlands drying out, water intrusion in coastal aquifers (Llopis-Albert & Pulido-Velazquez, 2013), and disappearance and regime alteration of related rivers, to water pollution (Hamm, Cheong, & Kim, 2005).

The Jumilla-Villena aquifer belongs to the regional governments of Albacete, Alicante, and Murcia due to its extension (Fig. 1). Southeast Spain has a mild Mediterranean climate. The Cretaceous carbonates aquifer has a surface of over 338 km^2, of which 108 km^2 are outcrops. The average aquifer thickness is 500 m and presents a syncline structural geology. The economically exploitable reserves range from an elevation of 450 to 100 m.a.s.l. (i.e., using pumping wells between 100 and 400 m depth). These water reserves are between 1200 and 2000 hm^3, with an average of 1600 hm^3. The aquifer is at extreme risk of not fulfilling the quantitative and qualitative environmental conditions of the EU WFD (See Table 1). Conflicting stakeholder interests are another problem because they impede the realization and success of any regulations. This situation gets worse when managing water resources are scarce. Regarding institutional considerations, the aquifer has user's communities, but the short means available to them constrains their actions. As a last resort, the aquifer water management depends on the river basin agencies. The Segura and Júcar river basins control the aquifer, leading to water transfers between them.

The criteria to select the relevant stakeholder groups include all the groups who will partially suffer measures implementation. Then, this study includes those groups whose interests, resources, and power/authority position may affect substantially measures implementation. This may include groups who have interests, claims or rights (ethical or legal) to the benefits of the measures undertaken, are likely to bear its costs or adverse effects whatever its overall worth. Eventually, the stakeholders participating in the Jumilla-Villena aquifer are: Segura and Júcar river basins, national administration, municipalities, environmental organizations or NGOs, recreational organizations, regional administration, agricultural representatives, industry, regional development organizations, and tourism organizations.

This study simulates four future scenarios (S) regarding pumping strategies with different exploitation levels. S1 entails a cessation of abstractions in the year 2004 and a recovery of the aquifer until the year 2025. S2 uses the abstractions of the year 2004 until 2007. Then, there is a cessation of abstractions and the recovery of the aquifer takes place until 2025. S3 uses abstractions of the year 2004 until 2007. Then S3 uses the abstractions of the Register of Water (RW) of the Segura river basin until 2015. The RW entails 65.35 hm^3/year. Subsequently, S3 simulates a half of the RW abstractions up to the year 2025. S4 uses abstractions of 2004 until 2007, a half of the RW until 2015 and a quarter of RW up to the year 2025.