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## Unconfined Aquifer Vulnerability Related to Topical Pollution— Montes Torozos (Spain)

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### Abstract

In this paper it is shown the vulnerability model fitted to the unconfined aquifer of Montes Torozos (Spain). The most dangerous elements were taken under consideration (e.g. Hydrocarbons, explosives, radioactive materials). The identification of their source location and the transportation of dangerous goods across them has been the starting point of this study. The simulations took into consideration the connection between the capital of the province (Valladolid) to Villanubla airport and between Valladolid to the electrical transformer substation, located in the south-west edge of the hydrogeological unit of the Montes Torozos.

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### 1. Introduction

The perception of water as a limited and fragile resource, due to deterioration by human actions, represents a limiting factor when considering the region's sustainable development.

The volume of water in Monte Torozos belongs to the Douroriver watershed and goes through the provinces of Valladolid and Palencia (Spain), occupying an area of 1000 km<sup>2</sup> (Fig.1). The population exceeds 47000 inhabitants

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spread over 48 municipalities. A dry Mediterranean climate predominates in the study area, with a median temperature value of 11.14°C, precipitation of 456 mm/year and evapotranspiration of 312 mm/year, as the main climatic features<sup>1,2</sup>.

The water balance shows 178 mm/year of useful rainfall that can reach and recharge the aquifer. Through processes of infiltration the substances present on the surface, accordingly to the respective dissolution constants and the particle size are transported, reaching the groundwater.

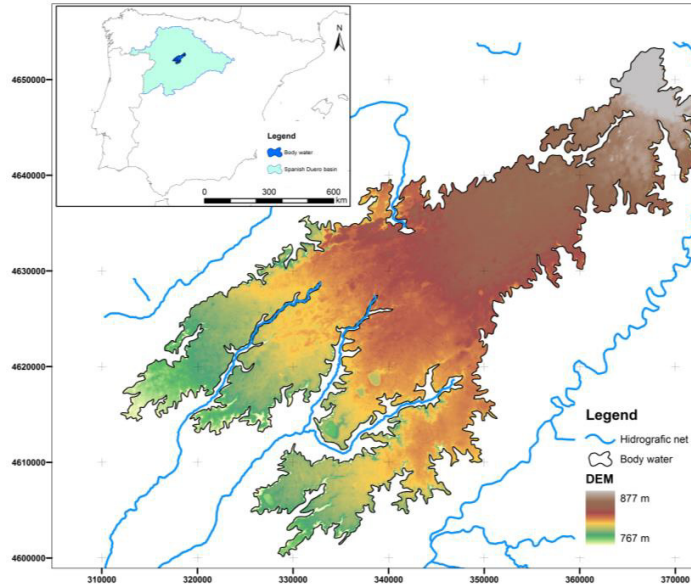


Fig. 1. Montes Torozos study area.

The Tertiary sedimentary free aquifer is included in the Douro river watershed with a slight tilting towards south-west. Geologically, could be considered as a horizontal limestone strata laying on a detrital mixed formation of evaporate facies of the Facies Cuestas<sup>3</sup>. The Facies Cuestas is the lower substrate formed by limestone and a series of soft clay loam-gypsum materials. The limestones are grey, hard and showing a microcrystalline structure in banks of varying thickness separated by marly intercalations. The area corresponds to a tectonic zone<sup>3</sup> only modified by diagenetic fracturation, allowing the development of karst channels<sup>4</sup>.

The aquifer is included in the Watershed's Management Plan 2009 corresponding to the old unit 07 of the Hydrological Plan for the Douro Watershed<sup>5</sup>. The Torozos aquifer (ID 400032), consists on horizontal limestone (Miocene) with loamy collations supported on the detrital Tertiary (units 06 and 08)<sup>5</sup>. Its overall thickness is approximately 6-10 meters, but can reach 30 meters promptly and works as an unconfined aquifer. The aquifer recharge is due to rainfall and drains radially, along the aquifer's perimeter, through spring and feeding the river's base flow and the extraction wells. The aquifer shows issues of quick crack of the water levels due to its low regulatory capacity. The amount of water resources is enough, showing an annual or biennial regulatory capacity, depending on rainfall to sustain the supply of the population, though. Due to its nature, the unconfined aquifer is extremely vulnerable to topical and diffuse pollution<sup>6</sup>.

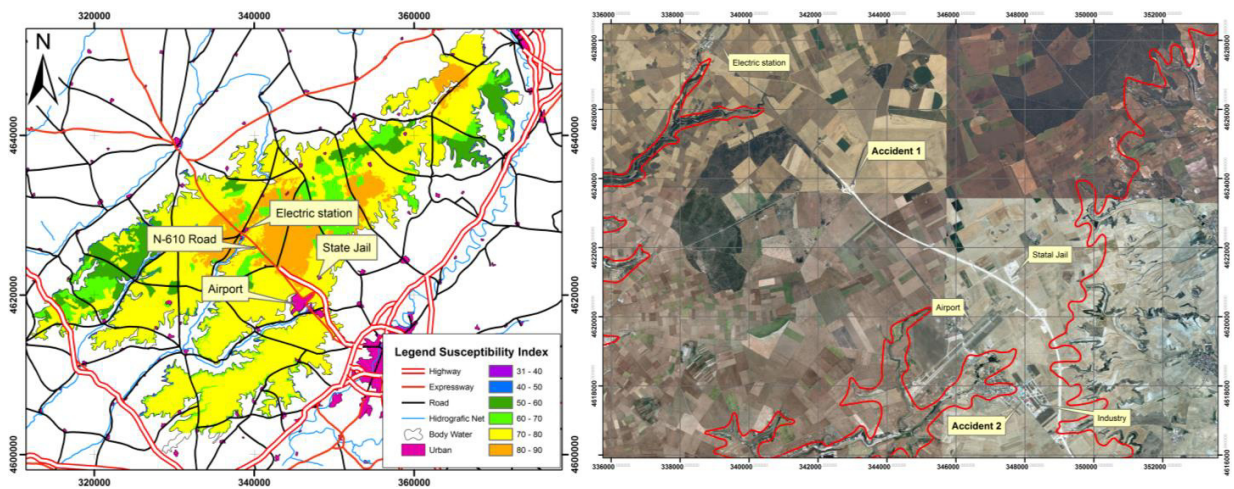
The occurrence of dangerous substances in core sites such as the airport of Villanubla, the electrical transformer plant of Mudarra, the Villanubla prison and the Villanubla industrial area combined with the traffic of dangerous goods through the entire area makes the Torozos aquifer a sensitive unit in need of accurate monitoring strategies.

The aim of this paper is a risk analysis and potential effects of an accidental spillage into the vulnerable aquifer of Montes Torozos using the DRASTIC<sup>7</sup> index map (Fig. 2). Considering the different nature of the impacting substances a contaminant type was chosen for the dispersion inferences mapping.

The regulatory framework governing road transport of dangerous goods in Spain is regulated by the European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) in its latest version of 2013. The Royal Decree 551/2006 laying down transport operations of dangerous goods by road in Spanish territory are regulated, and Royal Decree 1566/1999 safety advisers for the transport of dangerous goods by road, rail or in land waterway, as amended by the final first provision of the Royal Decree 551 / 2006 as stated in the National Institute for Safety and Health at Work. Dangerous goods are defined as substances and articles which transport by road is prohibited or authorized only under the conditions laid down in ADR or other specific provisions.

The identification of dangerous goods source location and the transportation of them has been the starting point of this study. This work aims the fitting of a numerical dispersion model for the most likely sources of emission and impact of pollutants into groundwater. The dispersion simulations took into consideration the connection between Valladolid, the capital of the province, to Villanubla airport and between Valladolid to the electrical transformer substation, located in the south-west edge of the hydrogeological unit of the Montes Torozos.

Fig. 2. Location map of vulnerability index and accident examples.



## 2. Methodology

The presented work is the result of a cross-sectional analysis of the processes of topical source pollution, associated with the transport of dangerous goods. In a first step, vulnerability was computed following the DRASTIC approach methodology<sup>8</sup>. Risk assessment related to the transport of dangerous goods was computed following the methodology described<sup>9</sup> and summarized in the equation (1).

$$R = P_{HG} \left[ P_e \left[ n_a \left( \frac{(H_i + H_t + H_r)}{3} + H_{GO} \right) + \left( \frac{\sum_i^n Vp_i}{n} + \frac{\sum_j^m Va_j}{m} \right) \right] \right] \quad (1)$$

Where: *R* Estimated risk level; *P<sub>HG</sub>* occurrence probability; *P<sub>e</sub>* Hazard level per accident; *n<sub>a</sub>* is a weighting factor; *H<sub>i</sub>*, *H<sub>t</sub>*, *H<sub>r</sub>*, y *H<sub>GO</sub>* Hazard level per product; *V<sub>p</sub>* y *V<sub>a</sub>* population and environmental’s intrinsic and extrinsic vulnerability.

Taking into consideration the legal background and simulacrum experiences carried out by the community of Castilla and Leon<sup>10</sup> it is possible to validate this methodology concerning the risk analysis associated to accidental releases of dangerous goods (class 7 of ADR).

The traffic of dangerous goods in the N-610 road (Fig. 2) has been estimated through the evaluation of the tax maps of 2012 (Ministry of Economic Development 2012)<sup>11</sup>. This itinerary has been selected as it is particularly sensitive

and vulnerable with moderate traffic (4500 vehicles a year). Therefore, it is possible to see that it has a priority path, although not the first choice one as it is a national road only partially utilized. Supply trucks cross through targeting the four major consumers such as the power plant, airport, prison and Villanubla's industrial area (Fig. 2). In the remaining study area, the road network shows mainly capillary flow of oil and gas supply.

A virtual topical discharge was considered for the pollutants simulation fitting. After choosing the emission focus, the pollutants' dispersion model was constructed accordingly to a steady-state model, previously fitted to the aquifer. Generally, the spread of contaminant propagation will be determined by the main flow direction, hydrogeological parameters and physic-chemical characteristics of the pollutants under consideration. For the hydrogeological model construction was used the Visual Modflow<sup>12</sup> supported by a geographic information system developed in gv-SIG software<sup>13</sup>.

### 3. Results and Discussion

#### 3.1 The hydrogeological model

The aquifer's hydrogeological conceptual model can be represented by the following scheme (Fig. 3), where the existing inputs and outputs are represented.

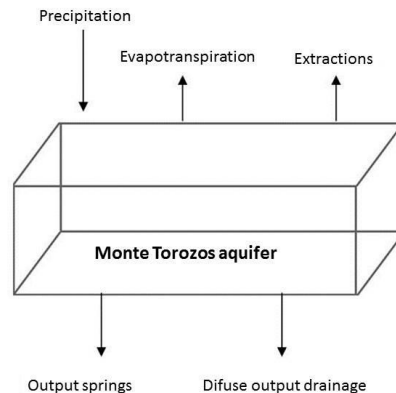


Fig.3. Aquifer's hidrogeological conceptual model.

The starting dataset concerns to the following attribute<sup>1</sup>:

- ETR - homogeneous and isotropic, estimated from the Turc's equation (312 mm/year)
- Recharge - homogeneous and isotropic precipitation, minus the ETR (178 mm/year)
- Edge Drainage - estimated (10 hm<sup>3</sup>/year)
- Initial Piezometric has been computed using visual modflow
- 211 pumping wells grouped into 63 wells fields (total extracted volume 9 hm<sup>3</sup>/year)
- 32 perimeter springs (output 10 hm<sup>3</sup>/year)

The computed outputs are: parametric evolution, flow vectors, fluid balance, and direction of the particles over a year (Fig. 4).

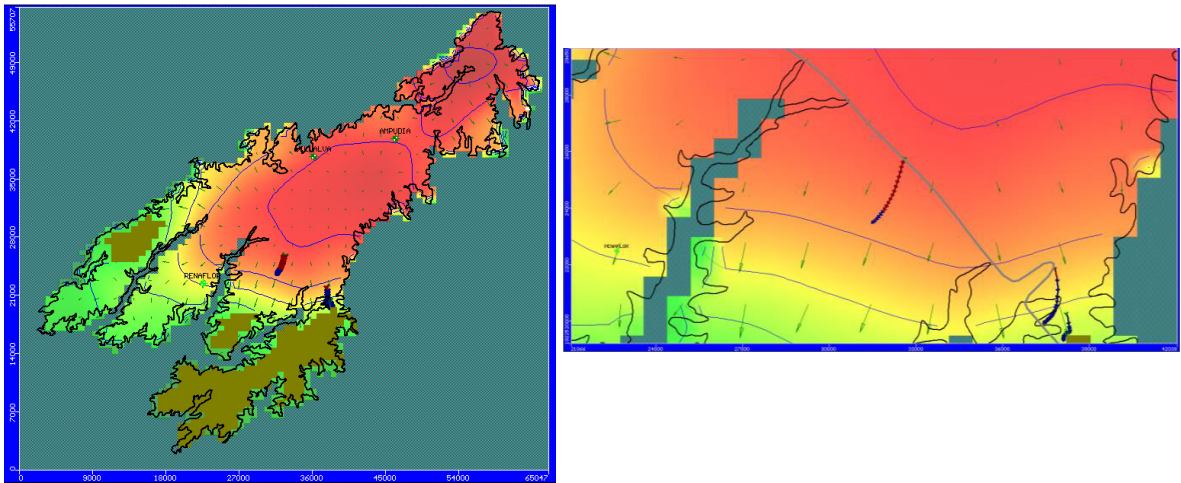


Fig. 4. Model outputs.

The nature of studied dangerous goods is highly variable. Adopting a theoretical constant solubility it is possible to study the dispersion rates for the substances under consideration. Taking into account the insolubility of the four major types of oxidized uranium, it was adopted an average solubility of 0.006g per 100 ml of uranium which is the solubility of the di-hydrate  $UO_4$  at 20° C. This low solubility, along with the very low frequency of accidents involved in transporting such goods, shows one accident for more than 74 transport operations in 2012 where more than 350000 kilograms of uranium oxides travelled throughout the Spanish territory<sup>14</sup>.

### 3.2 Risk Analysis

Considering the boundary conditions, the simulated worst scenario for the proposed accident shows:

- When the accident has occurred, the probability is  $P_{HG} = 1$
- The worst possible accident considered would carry a maximum value  $P_e = 6$
- The hazard by product type is considered as the maximum envelope of the materials of Class 7 and it would be  $R_{mp} = 3.5$
- The used weighting factor  $n_a$  takes a value of 4.
- The estimated vulnerability have an estimated value of  $V = 28$  (scale of 1 to 32), considered as extremely high

Therefore, the level of severity and risk estimated would be:  $R = 252$  on a scale of 0 to 288, considered as very high.

### 4. Conclusions

1. The studied aquifer is very vulnerable to contamination processes;
2. Due to the hydrogeological dynamics of the aquifer, the accidental releases of ADR's Class 7, have a very high gravity;
3. Despite the very low probability of an accident, there is a high risk due to the high vulnerability and slow pollutant's dispersion;
4. This slowness means lower short-term risk, but a very high long-term risk for both accumulation of such substances and it's deferred over long periods of time effects.

### Acknowledgements

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