



Regional Groundwater Flow Modelling of the Asturian Central Coal Basin (Spain)

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Abstract

Many of the world's coalfields are transitioning to closure, as is the case in the Asturian Central Coal Basin in northern Spain, which has been exploited since the 18th century. A management tool was needed to handle the many environmental and safety considerations associated with mine closure and to help identify opportunities for alternative water uses and new energy resources. This required an integrated framework to compile the huge amount of relevant information, which might otherwise be lost as mining companies move on to other things. Here we present such a framework, discuss the input data, and describe the conceptual model. The numerical model provides insights into the quality and distribution of the data. To illustrate its usefulness, the model was used to assess practical questions that are intrinsically non-local. For example, we employed it to estimate, at relatively shallow depths, the effect of stopping/regulating the drainage in one mine shaft on the remaining ones and on the nearby river. At much greater depths, we illustrated how the model could be used to quickly extract enough preliminary information to identify the best location in the watershed for a coal bed methane facility. The model is currently being employed to rationalize economic investment in improving/collecting field data sets and to help delineate boundary conditions for local-scale models for some of the watershed's more than 300 mines.

Keywords Numerical modeling · Groundwater management · Conceptual models · Comsol multiphysics

Introduction

Coal mining has been a very important economic engine for coal regions in the last two centuries. Cessation of this activity is, in many cases, a source of associated and interconnected problems for both society and the environment. Slope instability and mining subsidence can cause structural problems in the ground (Fathi-Salmi et al. 2017). The loss of active physicochemical controls can result in land contamination and other environmental problems (Li et al. 2019). Changes in surface flow dynamics can modify discharge

zones producing important flood events. Underground flow alterations can modify the location and the extent of both recharge and discharge areas (Younger and Wolkersdorfer 2004). Possible induced water pollution damages ecosystems and can be harmful to human health (Xiao et al. 2018).

On the other hand, once coal mining has been abandoned, these carboniferous areas become a very interesting framework for the exploitation of other resources, since they are usually located in areas near population centres. Mine water accumulated in the underground workings can be reused for supply depending on its quality (Ordóñez et al. 2012). The use of mine water as a low enthalpy geothermal resource is one of the most relevant applications, since it is a renewable and economical energy source (Loredo et al. 2016; Menéndez et al. 2020). The use of mining systems as underground reservoirs and electrical energy sources is another possible reconversion use (Menéndez et al. 2019). In addition, these areas might be used for CO₂ storage, contributing to mitigation of climate change effects (Bachu 2007; Perera et al. 2012). The extraction of methane present in the carboniferous layers, called coal bed methane (CBM), is another possible linked case of repurposing (Wang et al. 2014). Given

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the geographical areal extent of the mining activity and the broad range of depths involved (e.g. near surface for low enthalpy uses and thousands of meters deep for CBM) need a global-scale perspective to cope with interactions among them.

Accordingly, this work presents the first regional groundwater numerical model developed for the Asturian Central Carboniferous Basin (ACCB), which was the most important coal extraction area in Spain but is now ending activity. This regional model could be used by other researchers as a base framework for quick and approximate assessment of the more local models required by their projects. We show how it can be used to assess the boundary conditions of a local model and present two examples of its support in two kinds of local projects at two very different depths. First, the model was used to help find sensible surface locations for CBM exploitation at depth, given its potential induced effects on other activities going on in the shallower formations and on the surface. A second example, at a shallower depth, helps in the analysis of the risk of flooding arising from the hypothetical suppression of pumping in a mining system. The consequences, in both cases, show the model's relevance for assessing environmental, safety, and land management issues.

Materials and Methods

Study Area

The Asturian Central Coal Basin (ACCB) is located in the north of Spain (Asturias). Geologically it belongs to the Hercynian belt outer zone of the Iberian Peninsula within the Cantabrian Zone (Pérez-Estaún et al. 1988). The orography is complex and consists of large valleys embedded in the mountain system of the Cantabrian Mountains, with differences in elevation ranging from 150 to 2000 m above sea level (a.s.l.) The climate is oceanic, with abundant rainfall throughout the year (1000–1200 mm/year) and mild temperatures (3–14 °C).

The ACCB is composed of carboniferous materials that together are 5800 m thick. It is limited to the north by the discordant Cretaceous rocks of the central Mesotertiary depression (Gutiérrez-Claverol 1973), to the east by the Ponga region (Álvarez-Marrón et al. 1989), to the south by the Sobia-Bodon unit (Marcos 1968), and to the west by the Aramo unit (Aller 1986, 1993) (Fig. 1).

From the end of the 18th century until the present, exploitation of the coal layers in the ACCB has been of utmost importance. The number of relevant deep mines in the area exceeds 300, with an estimate of exploited coal of more than 420 MT (Fandos Rodríguez et al. 2004). The voids left after coal extraction will have modified the hydrogeological

behaviour at a regional scale. When active, huge volumes of groundwater were pumped out ($\approx 10^5$ m³/day average) from the underground formations to allow proper and safe coal extraction. Once closed, pumping rates are reduced to the minimum required to enforce drainage at certain safe levels.

Data

The collected information (> 2500 files/documents of different kinds and formats) consists of geological, mining, meteorological, and hydrological data, which the authors have searched and collected from various dispersed and often inconsistent sources. We developed a practical system for storage and classification of the very different types of documents found, through their arrangement in thematic directories and by use of a reference manager. This data management phase involves a very seldom acknowledged, huge amount of concealed “dirty” work that is essential for the correct definition of a numerical model, which must be based on organized and verified information. One of the critical steps is to bring the data into a compatible format and to correctly scale and represent it in real, consistent, and updated coordinates based on the collected mine maps.

Geological Data and Hydrogeology

The ACCB carboniferous materials consist of repeated sequences of shales, sandstones, and coal (65–70 layers), which alternate with layers of limestone in the lower half and with layers of conglomerates in the top half of the deposit. Two material groups are differentiated based on the different abundance of exploitable coal layers (ENADIMSA 1973; Garcia-Loygorri et al. 1971). The two groups show clearly different hydraulic behaviour: the so called non-productive or Lena Group (lower level) with a total thickness of 3000 m, decreasing in thickness towards the west (Aller 1981), and the so-called productive or Sama Group (upper level) with a thickness between 2400 m (east side) and 3400 m (west side). A description of the materials can be seen in Fig. 1c.

The study area is tectonically characterized by the presence of two important fold systems: longitudinal folding (E–W tension direction) associated with the Variscan orogeny and transversal folding (N–S tension direction) associated with the Alpine orogeny. There are also faults that affect the two systems of folds. In general, the entire area is intensely tectonized with numerous minor structures (Fuente and SáenzDeSantaMaría 1999).

The 3D geometry of the study area was established based on already existing geological information (Aller 1986, 1993; Aller and Gallastegui 1995; Alonso et al. 2009a; HUNOSA 2021; Pérez-Estaún et al. 1988, 1994) and additional field work carried out by the authors. In addition, several complete stratigraphic profiles were reconstructed by

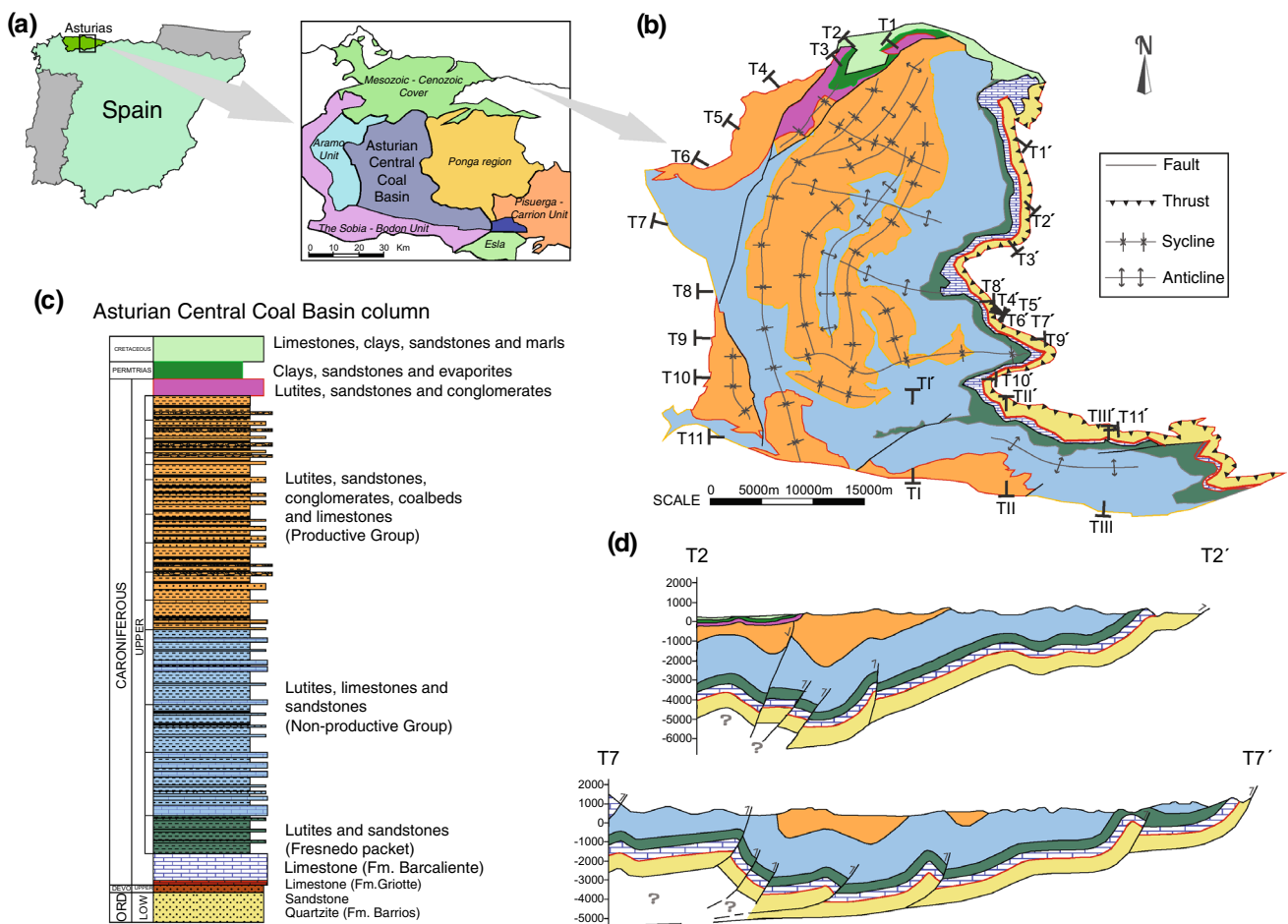


Fig. 1 Synthetic hydrogeological information. **a** Location map. **b** Hydrogeological map defining hydraulic zonation for the regional model. **c** Hydrogeological column. **d** Two hydrogeological profiles, as

examples. Note the Fresno formation, in green, employed later as bottom Boundary Condition

careful examination and integration of existing dispersed fragments of data. After treatment (organizing, editing, formatting, and correctly positioning), all of the information was put together and jointly interpreted from a hydrogeological perspective. Comments about the criteria for grouping together different geological layers into the same hydrogeological formation are detailed below.

This analysis provided the first 3D geometrical digital image of the ACCB hydrogeology, which is suitable for multiple purposes, including the development of conceptual models needed for numerical simulations. Due to its digital nature, the geometry may continuously be updated with new field work, geophysical characterization images, or any other source that can provide information interpretable in geological terms. All of the information was further synthesized, for ease of consultation, into a hydrogeological map (Fig. 1b), a hydrogeological column (Fig. 1c), and in 14 updated hydrogeological profiles, two of which are shown in Fig. 1d.

Mining Situation in the Study Area

The coal mining region has a plan area of $\approx 190 \text{ km}^2$, covering the bottom valleys where the big pits are located in the northern part of the study area. It includes 25 main mine shafts belonging to individual mines and to local mining systems that connect various neighbouring mines.

Exploitation of the coal layers, which slope steeply between 45° and 90° and have an average thickness of 1–2 m (Garcia-Loygorri et al. 1971), was carried out with different operating systems, the most common being overhand stopes and roadheaders. The careful examination of all and each of the documents regarding mining plans and detailed geometry of the interior workings has produced an error-free (we hope), consistent cartography of all the known interior mine workings and voids in the study area. The information about the mines’ interior included some very refined descriptions at a spatial scale of cm; this had to be interpreted to be upscaled, so that it could be integrated with larger spatial

scale geological information, to establish a hydraulic 3D zonation of materials altered by mining.

The average mine operating depth was ≈ 440 m, with a maximum exploited thickness of 720 m in the Lieres shaft. The availability of pumping and piezometric data was limited. There are 16 mining shafts in the area where pumping was measured by instrumentation and nine shafts where only pumping estimates based on volume-average interpolation of nearby mine shafts were available (Álvarez-Álvarez 2015). The average pumped flow was 3930 m³/day. There are 15 shafts in which the water level is periodically measured and ten shafts for which estimated water level bounds are specified. This is also dependent on their status (flooded, flooding, or dry). The average water level was between 100 and 300 m a.s.l. in the flooded shafts and between -200 and -375 m

a.s.l. in the dry shafts, corresponding to the lowest level of the mine workings.

After error cleaning and processing, the information was classified and stored in a database, allowing it to be synthetically accessed in the more visual form of maps and graphs, such as in Fig. 2. Information from different individual mines, up to now only available piecemeal as isolated shaft-dependent data, is now integrated at the watershed scale and amenable to comparisons or for use by the companies/institutions involved.

Meteorology and Hydrology Data

Precipitation and temperature data have been collected from 18 weather stations located in or near the study area

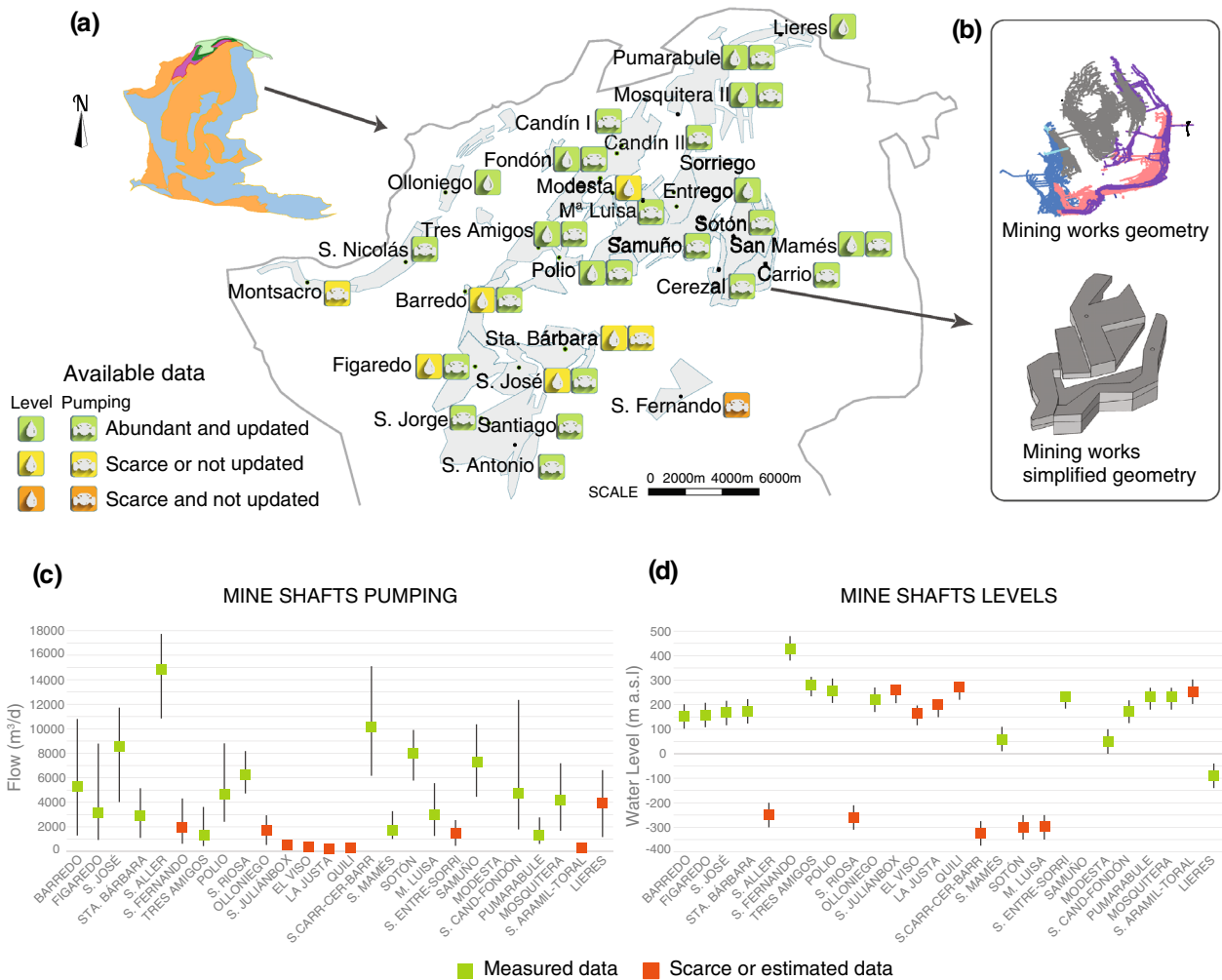


Fig. 2 Mining information. **a** Synthetic map with all the mines in the study area including qualitative ranking of the degree of information available, allowing updating and improvement whenever possible as interaction with the mining companies still evolves. **b** Detailed mine workings geometry for a single pit and simplified zonation for

regional model. **c** Average pumping rates in every mining system together with their estimated uncertainty bounds (seasonal amplitudes). **d** Average water levels with estimated uncertainty (seasonal amplitudes)

(Fig. 3a). The data series were subjected to statistical treatment and completed using methods based on linear correlation. To obtain a relationship of precipitation and real evapotranspiration (RET) to elevation, an auxiliary 3D linear interpolation was set up (MathWorks 2020).

Potential evapotranspiration (PET) was calculated according to Thornthwaite (Poehls and Smith 2009) and RET, according to Le Turc (Maidment 1992). Infiltration to the groundwater system was derived from precipitation data by subtracting the water fraction that does not infiltrate due to evapotranspiration and surface runoff (Poehls and Smith 2009). The calculated infiltration map is shown in Fig. 3b. Some locations present anomalous values (red areas in Fig. 3b) due to identified 3D linear interpolation artifacts produced by the scarcity of high-altitude data. For this reason, these values were discarded to obtain a range of infiltration between 0 and 500 mm/year, with an average value of 250 mm/year. Previous local-scale studies have suggested a deep recharge to mining systems of ≈ 100 mm/year, based on the pumping rates for active mines and local catchment areas (HUNOSA et al. 2009a, b, a, b, c). A similar analysis for the mining system as a whole, using a flow of $\approx 10^5$ m³/day, and a catchment area of 270 km² gives a slightly higher value of ≈ 135 mm/year, which should be considered a rough estimate. The difference between infiltration and deep recharge provides a first estimate of the flow that discharges to the surface runoff system through those ancient shallow mining

systems, and still remains unaccounted for because of a lack of awareness or a lack of precision in their characterization.

The hydrographic network consists of four important rivers (Fig. 3a); their calculated gauged averages for the period from 1970 to 2020 are: (1) Nalón river, $Q = 18.47$ m³/s, (2) Lena river, $Q = 5.29$ m³/s, (3) Aller river, $Q = 8.79$ m³/s, and (4) Caudal river $Q = 22.36$ m³/s. There are 12 gauging stations in various tributaries, of which only five are rigorously useful for river characterization because they have a representative range of correctly calibrated data (CEDEX-Área de Recursos Hídricos 2020; Confederacion Hidrográfica del Cantábrico 2020).

To extend the range of data, we assumed that the ratio between average flow and instantaneous maximum flow is usually more or less constant in most of the basins (CEDEX 2011). This allowed us to calculate flows for the five gauging stations where both maximum and average flows are available and then extrapolate the flows to the remaining rivers. This is deemed an unsatisfactory though sufficient starting point for running the numerical model and to highlight to the watershed authorities a well-supported claim to improve this situation.

In addition, there are two reservoirs within the limits of the study area, used for water supply and hydroelectric generation, the Rioseco reservoir, located to the east at ≈ 380 m a.s.l. and the Porma reservoir, located on the southeast edge at ≈ 1080 m a.s.l. (Fig. 3a).

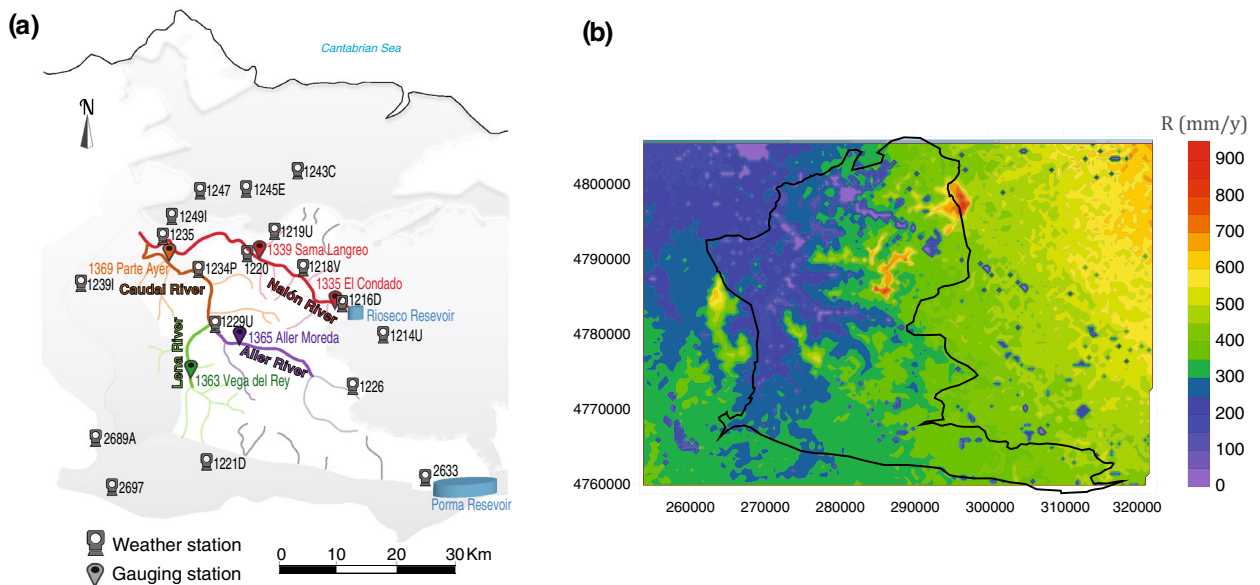


Fig. 3 Meteorology and hydrology information **a** Weather and Gauging stations, rivers, and their tributaries. **b** recharge mesh in mm/year

Conceptual Model

A conceptual, 3D, steady-state flow model (Fig. 4) was defined based on the collected data and model goals. The phreatic surface is usually very close to the surface, so the model does not include vadose zone processes. Each formation is considered as homogeneous and isotropic.

Darcy’s law is, at this scale, considered always valid. The carboniferous materials were considered from the equivalent porous media point of view and three hydrogeological units were identified:

- A lower part corresponding to the *non-productive group*, with a much higher amount of limestone layers and fewer coal layers was assigned a hydraulic conductivity range of 10^{-2} to 1 m/day.
- The upper part, the *productive group*, with limestone layers gradually replaced by conglomerate and coal layers, was assigned a reduced hydraulic conductivity of 10^{-3} to 10^{-2} m/day.
- Material altered by mining activities and surrounding mining systems were assigned an increased hydraulic conductivity of 10^{-3} to 1 m/day.

With regard to boundary conditions, a Dirichlet boundary condition (BC1) was initially used for the water reservoirs, with values of $H = 350$ m a.s.l. in the Rioseco reservoir and 1080 m a.s.l. in the Porma reservoir. The same was done for the mining shafts where measured water levels are available.

A Neuman boundary condition (BC2) was applied to the areal limits of the model to the top surface with a spatially distributed recharge and in those mining shafts where the pumping rates were measured and available. The northern limit was established as a no-flow edge because of the existence of an antiformal fold that acts as an underground groundwater divide (see sketch, Fig. 4b). The eastern border was established where the deepest, thick, and impervious “Fresnedo” formation outcrops, and was considered as a no-flow edge (Fig. 4a). The base of the model is made of the same impervious formation. The “Fresnedo formation” is in the lowest part of the non-productive or Lena Group and consists of a 470 m thick layer of shales (Garcia-Loygorri et al. 1971).

In the southern border, carboniferous materials come into contact with lower Paleozoic materials that have a very low permeability (at least two orders of magnitude less than average carboniferous materials) and so, the boundary was considered as no flow. The western border was also considered

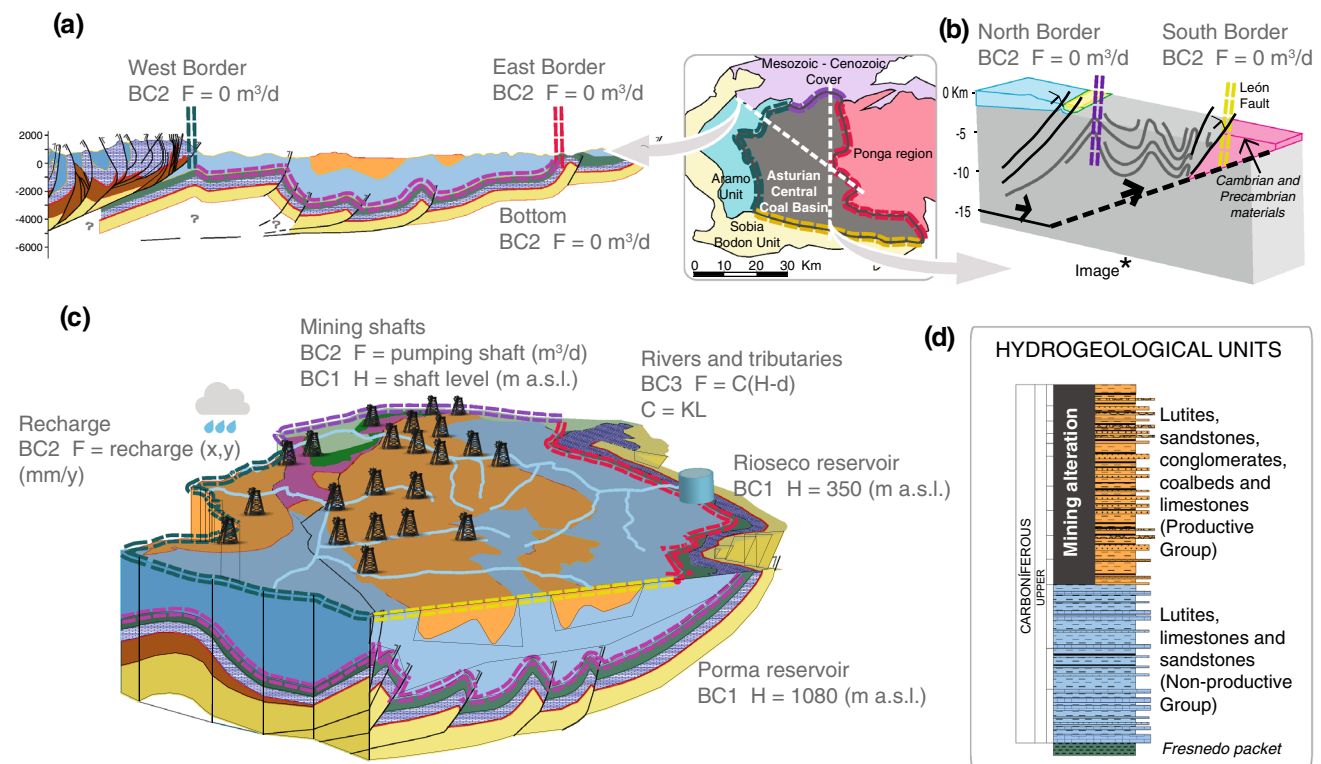


Fig. 4 Conceptual model. **a** Illustration of the Eastern (red dashed segments) and Western (green dashed segments) BC. **b** Same for Northern BC (magenta dashed lines) and southern (yellow dashed

line). **c** 3D view of the BC relative to the Basin. Bottom. **d** Hydrogeological units. The image labeled "asterisk" is modified from (Alonso et al. 2009b)

a no-flow edge, having previously been evaluated by numerical simulations confirming an extremely low flow of <3% of the total flows within the study area (Álvarez-Álvarez and Fernández-Álvarez 2018b). A Robin boundary condition (BC3) was used for the rivers with an equivalent conductance calculated based on the hydraulic conductivity of the formations they traverse.

Numerical Model

The conceptual model described in the previous section was implemented using COMSOL Multiphysics® modelling software and calibrated with the pumping rates and hydraulic heads measured in the mining shafts or systems. The resulting numerical model is 3D. The mesh consists of 374,582 quadratic tetrahedral elements with a maximum element size of 4480 m and minimum element size of 560 m (Fig. 5a). The average parameterization used were $K=0.1$ m/day for the non-productive group, $K=0.001$ m/day for the productive group, and conductivities for working-mine domains that depend on the degree of mining alteration, ranging from $K=0.001$ – 0.1 m/day.

The selected calibration criteria require that the pumping and heads predicted by the model fall within the

uncertainty bounds plotted in Fig. 2c, d. The transmissivities of this model have been estimated by a “trial and error” process (Anderson and Woessner 2002). Although the results are subject to non-uniqueness (in terms of the relationship recharge/transmissivities) due to the excessive concentration of available measurements in the northern half of the domain and of their uncertainty at present, the proposed model is a sensible representation, compliant with the data (Fig. 5). It will be used in the very near future to contribute to design and optimization by the process of rationalizing investments for the acquisition of new data/information, particularly in the southern, much less constrained, part of the model.

The graphs show an isolated anomaly at the measured Pumarabule pumping rate (calibration by flows). The two shafts, Pumarabule and Mosquitera, which are plotted separately in Fig. 5, belong to the same interconnected mining system (González-Quirós and Fernández-Álvarez 2019). In a regional model, they should more properly be treated as a single system. In doing so, the aggregated pumping flows are inside the error bars.

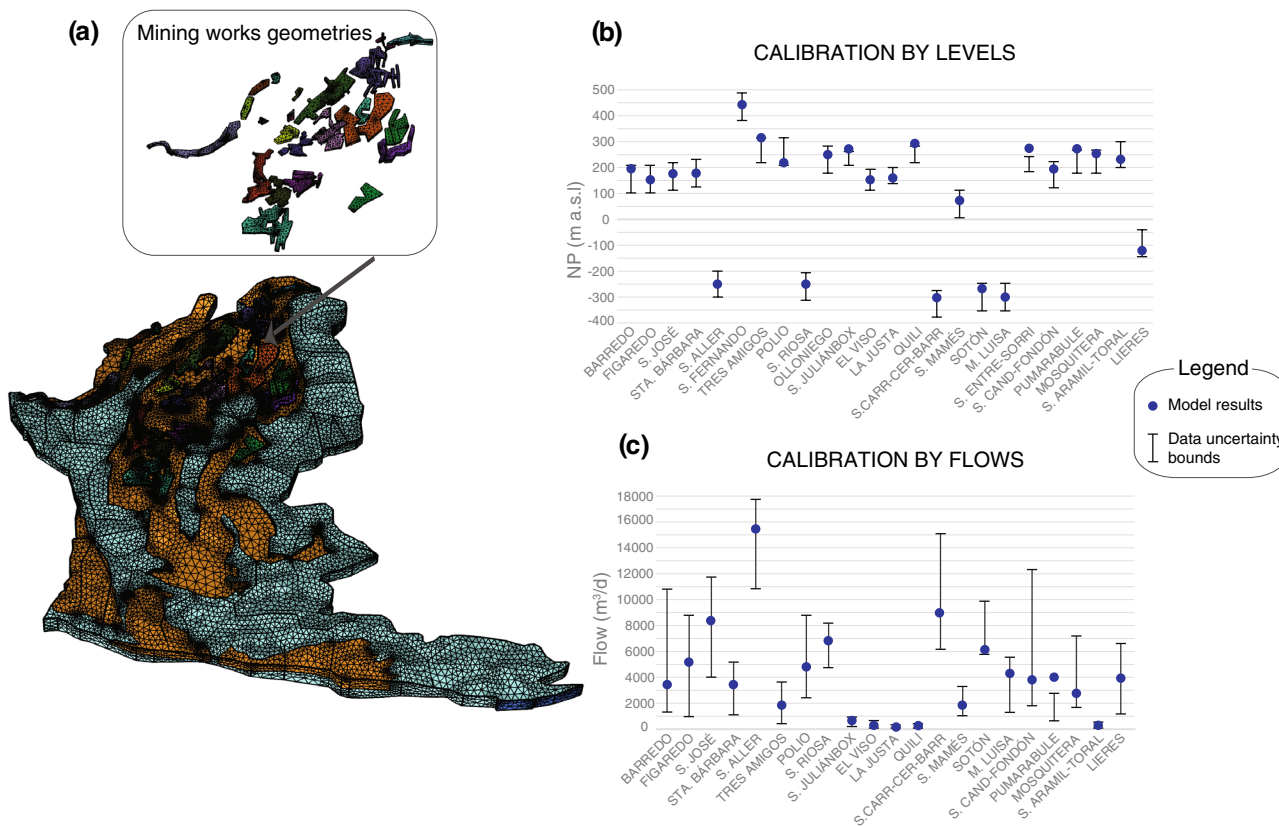


Fig. 5 Numerical model. **a** Coal Basin Flow finite element mesh. **b** Calibrations by hydraulic heads with uncertainty bounds. **c** Same, for flow calibration

Results

The numerical model allows for the understanding of regional flow dynamics, with the main flow direction being S–N oriented (Fig. 6a). Thus, groundwater flowing in the southern half of the study area would be less affected by possible effects of coal mining (river and hydrogeological dynamic alterations, pollution, etc.). In addition, operations in these shafts would mainly affect other shafts situated farther to their north.

In the SE zone of the study area, the model predicts a groundwater divide (Fig. 6a) between the two slopes of the Cantabrian Mountains, where it would be sensible for it to appear, which supports the quality of the model.

During the calibration stage, it was seen that input infiltration described earlier produced anomalously high piezometric levels at certain locations (see Fig. 6b). This suggested excessive infiltration recharge to the model in those areas. A more careful local inspection showed the existence there of significant areas of old coal mine surface-workings and reclamation, which would cause a part of the infiltrated water to emerge through a very shallow path at the surface, before becoming deep recharge. Again, the model results provided insight into local behaviours/hydraulic properties.

Using the calibrated model, two predictive simulation scenarios were considered in this study: (1) shallow zone—temporary suppression of pumping in one mining system, and (2) deep zone—coal bed methane extraction.

The first simulation for the regional model was the hypothetical suppression of pumping in the so-called M. Luisa—Sotón system and its effects on nearby coal mines (Fig. 7). The model identified the shafts where pumping rates would have to be readjusted to keep the water levels

at the safety thresholds. The effects on the river behaviour were also evaluated (Fig. 7c).

The model indicated that the flooding of the M. Luisa—Sotón mining system would cause an increase in the pumping rates of certain mines or mining systems by +188.8 m³/day (0.52% of the total involved). Including the suppressed pumping rate, the calculation shows a significant decrease of 4018.4 m³/day (11.08% of the total) in the total water pumped. This translates into significant energy savings (Fig. 7d).

The flooding of the mine would increase the outflow to the river, particularly in the area where the river passes closest to the affected area (+601.8 m³/day—15.56% of total). Using a calibrated gauging station (number 1339) in the area, it was possible to see that this increased river flow would increase the water level there by less than 1 cm and would thus pose no additional risk of flooding.

To illustrate a management scenario for the deep zone, a preliminary assessment of feasible locations for a CBM extraction facility was performed. It is known that certain coal layers in the productive group inside the ACCB watershed might have commercially viable methane content (Cienfuegos and Loredo 2010) and thickness (40–50 m). The model was used to explore and propose feasible locations. For logistical and social issues, it would be much better to have these places near already exploited mining systems. This, in turn, brings forth a number of technical issues, one of which is to find the depth of the production screen in the CBM borehole so that, on the one hand, it does not affect the water already stored inside the closed workings above it and, on the other, remains within a depth judged economically feasible.

Figure 8 shows, as an example, the results from a typical simulation performed near one particular shaft in the watershed. In Fig. 8b, it can be seen that the coal seams dip between 50° and 60° to the east and that the (already

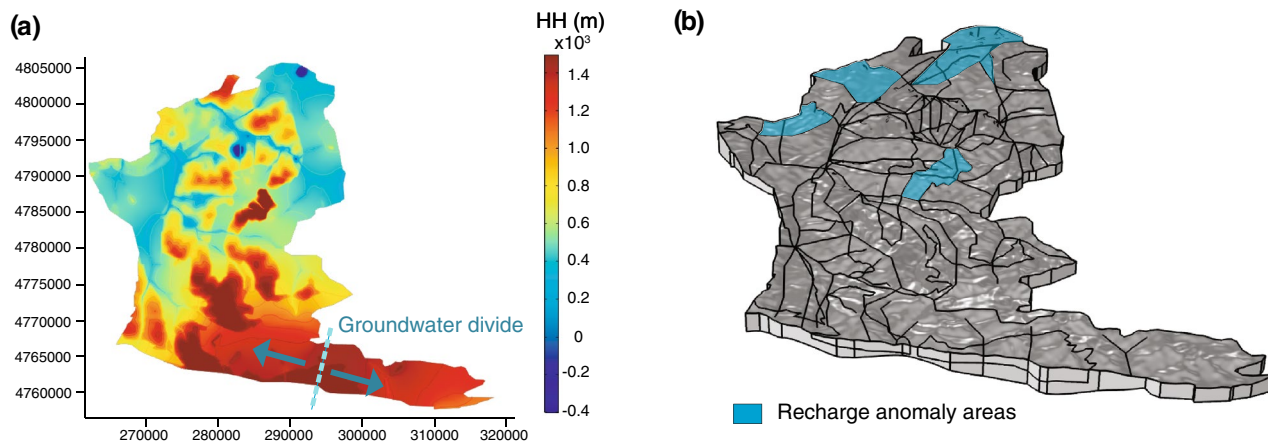


Fig. 6 Numerical model results. **a** Hydraulic Head map and groundwater divide position. **b** Recharge anomaly areas

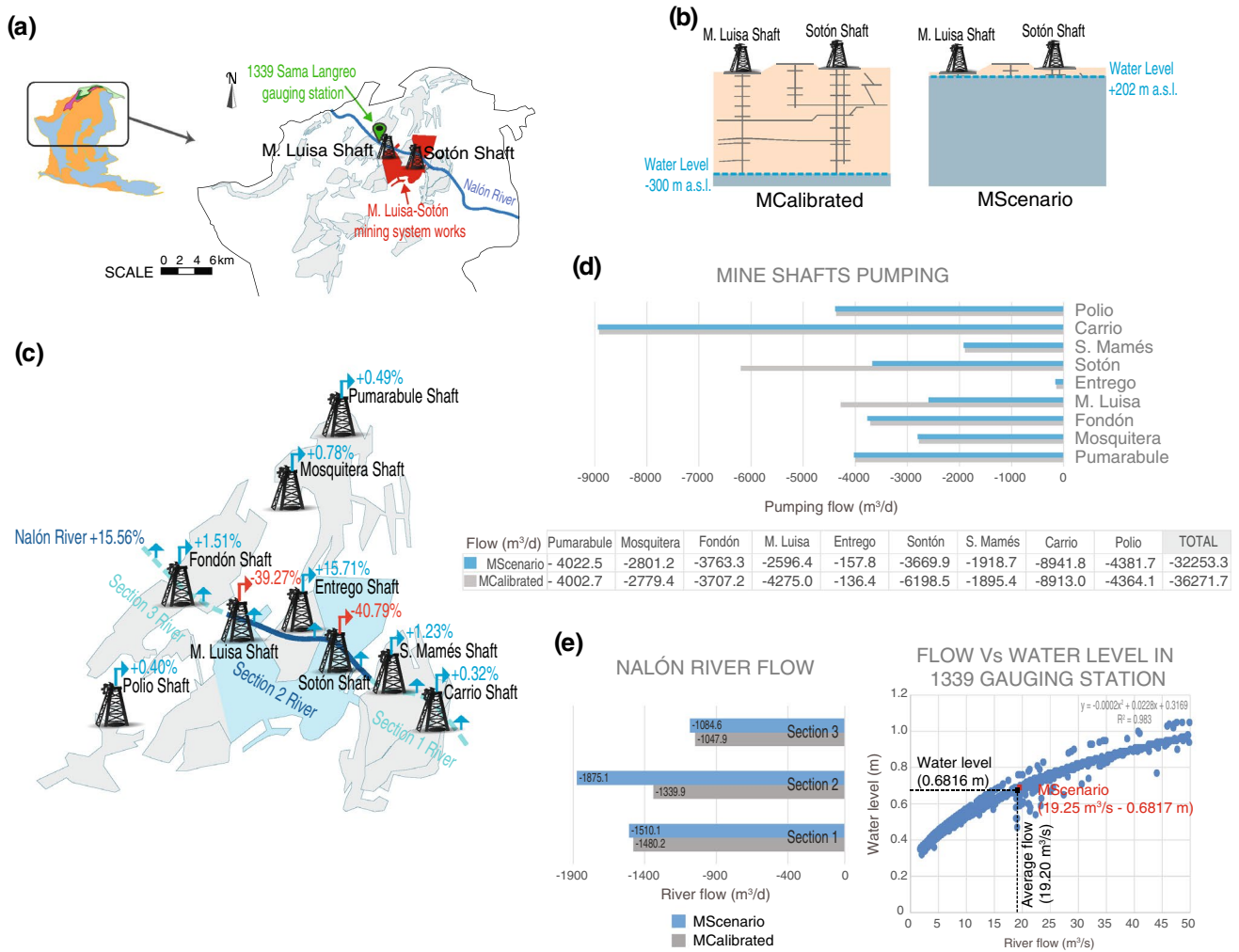


Fig. 7 Shallow zone management scenario: suppression of pumping in M. Luisa—Sotón shaft. **a** Situation map. in red, MLuisa—Sotón mine workings. In blue, the Nalón river. Gauging station no. 1339 in green. In grey, the remaining mining systems. **b** The Shaft would stop pumping and flood up to the safety level of +202 m a.s.l. **c** Impact

in other shafts and river on the flow rates. **d** A slight increase is observed for the shafts mentioned. **e** Water level at the gauging station 1339, downgradient of the mining area superimposed on the calibrated data curve

flooded) mine workings have reached a level of ≈ 200 m a.s.l. A standard CBM setup was run as an illustration (see Fig. 8c) with specifications obtained after an in-depth bibliographical review. The water head at the pumping well was lowered to 40 m above the production screen to ensure that conditions for gas desorption were met. The artificially fractured area was specified through the half-length fracture (75 m here) and a thickness of 24 m (SáenzDeSantaMaría 2001). In that stimulated volume, the hydraulic permeability can be increased up to 800%. Different depths for the production interval—from -1200 to -800—were tested. Figure 8d shows results with high practical interest. For the different screen depths tested, the vertical influence area, defined as the area that would see a decline in piezometric

head of at least 5 m in steady state flow (OGIA 2009) were plotted.

If the level of the production screen gets closer to the surface (-800 m a.s.l.), the mine bottom will, in the long-term, fall inside the vertical influence area, which would greatly increase the flow of water from the free water stored in the flooded workings, to the CBM facility, probably making the CBM project uneconomic.

This safety threshold depth depends on the increase of hydraulic conductivity in the stimulated volume, which may be a control parameter. Figure 8e shows, for each hydraulic conductivity change achieved, the corresponding safety depth. Higher stimulation implies drilling deeper. The corresponding flow rates pumped out were also calculated for

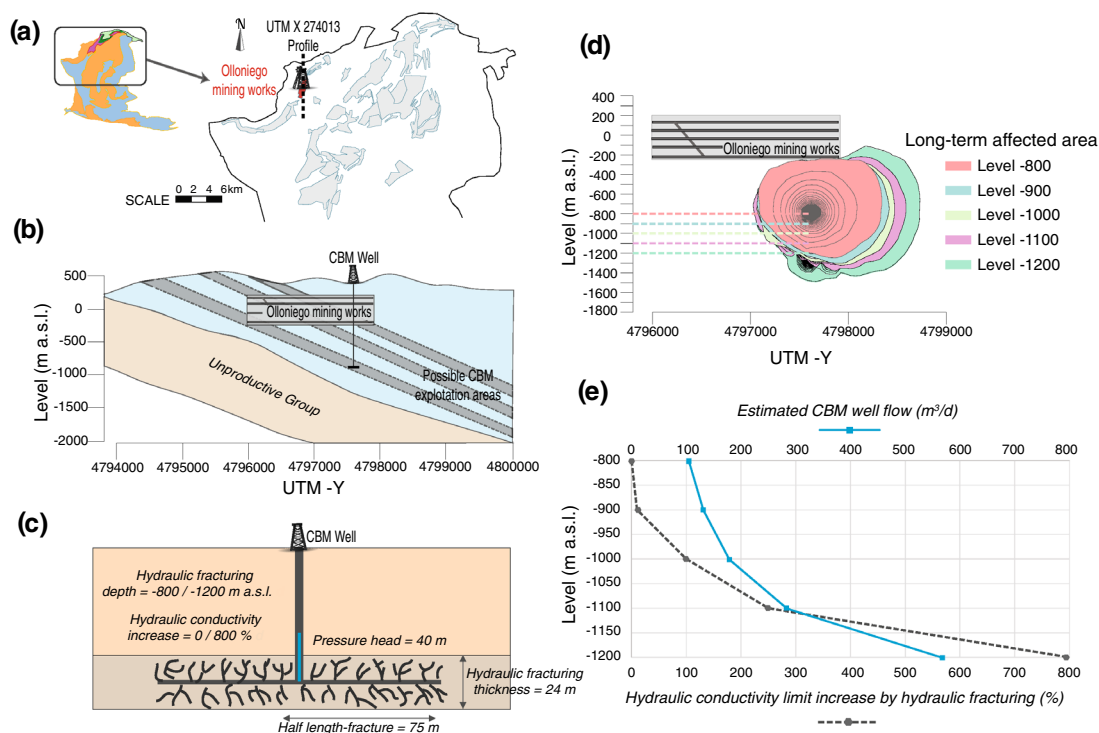


Fig. 8 Deep zone management scenario: coal bed methane extraction. **a** Location of the mining system to be protected from CBM extraction influence. Dashed line is for profiles **b** and **c**. **b** Diagram of the different optional layers (depths) available in that profile, from the model geometry **c** CBM technical standard specifications for illus-

each case (in blue) and were always in the range of 100–600 m^3/day .

Discussion and Conclusions

This regional groundwater model built using the COMSOL Multiphysics® simulation code, of the Asturian Central Coal Basin (ACCB), provides an understanding of the regional flow system and constitutes a basic tool for water resources and land use management in this area. The basin, hosting for more than a century the most important coal-producing field in Spain, is now facing the impact, at all levels, of their closure. Environmental and safety concerns, as well as the assessment of new uses of the mining sites, including alternative water uses and new energy resources, will clearly benefit from it.

The model allows evaluation of different development scenarios in the study area and should be capable of tackling questions not appropriate for any local model, while contributing to these local models and constraining them. It was only created by searching and integrating all of the available information, although that data was heterogeneous

and dispersed. This geological, mining, and hydrogeological information was catalogued and appropriately included in a database, which has made it possible to detect the need, in the southern zone and in the Nalón and Aller valleys, for improvements in the quantity and quality of the hydrological and mining data (river gauging, hydraulic heads, and mine pumping rates) being collected. This insight will help optimize efforts and economic investment in future field work and information/data collection.

A conceptual model was built from careful analysis of multiple data sources of varying quality and was encoded into a numerical groundwater model to provide further insight into the regional groundwater system. The numerical model allowed identification of the main regional flow directions (from S to N). The model also showed areas where the usual recharge input gave rise to anomalous piezometric behaviour. These areas proved to be linked to old, previously unnoticed shallow-mined areas.

This calibrated numerical model also provides a way to answer questions that are intrinsically non-local in nature, both in lateral extension and depth, such as evaluating the effect of a temporary pump stop in one mining system on other mines (shallow zone application) and on the rivers (Fig. 7). In

addition, the model can be used to identify preliminary locations in the watershed where CBM installation facilities could be placed.

Analysis of the hypothetical suppression of pumping activity in one shaft showed the increase that would be needed in the pumping rates at adjacent mine systems to keep the water level below the safety threshold. In this situation, the model showed that the total pumping rate (additional pumping in adjacent mines minus the historic flow from the stopped pumps) would be reduced, producing likely energy savings. The effects on the river were shown to be modest and unlikely to significantly increase the risk of flooding.

The analysed scenario for a deep zone involved performing a preliminary assessment on the placement of a hypothetical CBM facility. The example scenario predicted the impacts of a CBM facility with standard specifications, including the acceptable depth of the screened production interval of the CBM, so as not to perturb water storage in nearby shallow mining systems, which may already be used for other purposes (such as geothermal supply, for instance). Other considerations in choosing an acceptable depth include the additional volume of water that would have to be extracted. Additional interesting variables could easily be added to the predictive model.

This groundwater model is currently being further developed with other applications in mind such as: the analysis of deep geothermal wells for which a coupled flow-heat model would be needed. The model also provides insight into boundary conditions for small-scale detailed local models where needed.

The transformation of the ACCB from active mining to closed mines brings opportunities for new mine water use as a geothermal resource or supply, carbon dioxide storage in coal layers, or coal bed methane extraction. Understanding the impacts of such developments, requires, in many cases, detailed knowledge of the flows that occur within the mining works. This requires local-scale models with detailed definition of the mining geometry. Local boundary conditions in an area with these characteristics is a complicated and difficult task. Therefore, the regional scale groundwater model built in this work will be very useful for defining boundary conditions in smaller scale models.

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