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1 **Initiating collective action for the management of deep confined aquifer systems: application of a**
2 **participatory scenario approach in France**

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13

14 **Abstract**

15 Large deep confined aquifer systems play a crucial role for water and food security and the economic
16 development of rural areas. However, there are few cases, worldwide, of integrated management
17 and governance of such groundwater resources. This paper first investigates factors that hamper
18 stakeholders' involvement in groundwater management, in particular deep confined aquifer systems
19 that extend over a large regional area. It then shows how participatory scenario analysis can be used
20 to trigger collective action by regional actors. The paper relies on the case study of a large confined
21 aquifer in South West France impacted by multiple pressures from the drinking water, energy,
22 agriculture, and health sectors. It is shown how participatory scenario analysis contributed to
23 building a shared understanding of the resource amongst regional actors and generated a collective
24 view of the main groundwater management challenges. Results also suggest that engaging
25 stakeholders in futures thinking at the beginning of the participatory process is a powerful approach
26 to generating a commitment for collective action on groundwater.

27

28 **Keywords**

29 Common pool resources; Socio-economic aspects; Participatory Methods; Future studies; France

30

31 1. Introduction

32 Confined aquifers in particular represent a strategic resource in many parts of the world given their
33 natural protection from human pollution and their potential role as buffers against the impact of
34 climate extremes. Where surface water systems and shallow aquifers have become over-allocated or
35 polluted, deep confined aquifers still provide a valuable alternative source of water. The strategic
36 importance of these deep confined resources has been recognised in different regional contexts,
37 such as the Great Artesian Basin in Australia (Robertson, 2020), the Nubian and Sahara Aquifer
38 System (Nijsten et al 2018) or the Guarani aquifer system in Brazil and neighbouring countries
39 (Sindico et al 2018). Yet, successful examples of deep-aquifer sustainable management are few, and
40 concern is growing worldwide on the emerging global groundwater crisis (Famiglietti 2014).

41 The integrated management and governance of deep, confined aquifer systems faces several
42 challenges (Jakeman et al 2016; Lapuyade et al 2020). Detailed mapping and monitoring is difficult to
43 achieve due to their depth and complex hydrogeology. The boundaries of confined aquifers, where
44 known, rarely match those of surface water basins around which water management actors usually
45 manage water resources. Furthermore, depletion from deep aquifers does not create immediate
46 visible impacts, unlike with shallow aquifers where depletion usually affects dependent ecosystems,
47 triggering a quick response from social groups who depend on those ecosystems. Due to all these
48 factors, public and private actors concerned with confined aquifers may not necessarily realise the
49 risks resulting from the overexploitation of the resource. As a result, regulators, politicians, economic
50 users and their representatives may have a low willingness to invest time and resources in the
51 development of restrictive groundwater management plans.

52 To engage stakeholders in groundwater management, the most classical approach assumes that they
53 must be trained to acquire basic scientific and technical knowledge required to understand the issues
54 at stake and develop their own opinions (McClurg and Sudman 2000; Aureli et al 2008; Re and
55 Misstear 2017). However, this learning process requires a significant investment that the actors will
56 only agree to make if the problem becomes "higher priority" than others with which it is in
57 competition. To do so, they must be convinced of the usefulness and potential impact of their
58 participation. This requires an awareness (1) of the risks associated with inaction, (2) of their ability
59 to influence the future of the system, and (3) of the existence of levers to change the course of
60 events. The approach defended by the authors of this article is that participatory scenario analysis,
61 focusing on the long term evolution of the resource and its uses, is an approach that can arouse
62 curiosity and interest in groundwater issues and, ultimately, facilitate the engagement of
63 stakeholders in collective management.

64 This article tests the use of participatory scenario analysis to make groundwater, in particular deep
65 aquifers, "visible" (Lopez-Gunn 2009) to stakeholders and initiate their integrated management.
66 Stakeholders involved include users from different sectors (agriculture, drinking water supply, spa
67 industry, energy), representatives from local governments and state agencies (regulators). The case
68 study, in South West France, relates to the protection of three connected large-scale, deep confined
69 aquifers, that are strategic for drinking water supply given their high quality water and geographic
70 extension. The area is characterised by a highly heterogeneous hydrogeology impacted by multiple
71 pressures from the drinking water, energy, and agriculture sectors, and the spa industry. The paper
72 presents an inter-disciplinary methodology based on pre-defined scenarios debated in workshops for
73 engaging actors and creating a shared vision of the strategic importance of the sustainable
74 management of these deep aquifers.

75 The article first analyses the challenges in engaging actors in groundwater management, focusing on
76 deep, confined aquifers, and reviews the role that participatory scenario analysis can play in initiating
77 collective action for their management. It then presents in detail how participatory scenario analysis
78 was used in the French case study, including the steps in creating a shared knowledge base and
79 engaging users in identifying common principles for the future management of the aquifer. It
80 concludes with the potential for such an approach to be applied more widely for sustainable
81 management.

82

83 **2. Engaging actors in collaborative groundwater management**

84 There is a consensus among policy makers, practitioners and scholars that users and other actors
85 having a stake in groundwater management should be closely associated to the resource monitoring,
86 the discussion of scenarios, the definition of management targets and interventions, the
87 implementation and evaluation of action plans and their adaptation (Barthel et al 2017). This section
88 analyses the factors that may impede the emergence of this collaborative governance, focussing on
89 confined aquifers. It then shows how scenario planning can facilitate the emergence of collaborative
90 governance.

91 **2.1. What are the challenges?**

92 Experienced basin managers commonly agree that it is more difficult to involve stakeholders in the
93 management of deep confined aquifers than in surface water resources or shallow aquifers. Several
94 challenges specifically related to confined groundwater resources are put forward.

95 The first challenge is related to the lack of knowledge both stakeholders and scientists have on deep
96 confined aquifers. Because they are complex objects, located at greater depth, stakeholders are
97 highly dependent on experts and their scientific tools (piezometric networks, geological profiles,
98 mathematical models) to understand their dynamics. This complexity is linked to the three-
99 dimensional geometry of groundwater bodies, the possibility of interconnection of several reservoirs
100 in multilayer aquifers, the phenomenon of captive flow (under pressure), and to the particular ways
101 in which groundwater interacts with surface waters. These characteristics are not intuitively
102 understood, and their communication requires more effort than for surface water and shallow
103 aquifers, and also the use of specific visualisation tools (Baldwin et al 2012; Richard-Ferroujji and
104 Lassaube 2020).

105 The challenge also lies in clearly defining uncertainties and acknowledging knowledge gaps (Foster
106 and Chilton, 2018). While stakeholders exploiting wells (public water utilities, farmers, industries)
107 may have a good vision of how the aquifer reacts locally, they rarely understand groundwater
108 dynamics at a regional level. Scientific hydrogeological knowledge remains more fragmentary than
109 for surface water or shallow aquifers, as hydrogeologists only have a partial 3D view of the reservoir
110 through scarce deep drilling logs, piezometers and pumping tests. This is contrasting with shallow
111 aquifers and surface water bodies which are more easily accessible for observation. Significant
112 uncertainties may thus exist regarding the spatial extension of deep aquifers, their temporal
113 dynamics and the size of resource stock. It is also difficult to assert with certainty the spatial flow
114 dynamics, the interactions between extraction points and the impact of extraction on total aquifer
115 storage.

116 The second challenge is the lack of public awareness of groundwater issues (Suvedi et al 2000;
117 Dickerson et al 2007; Arthurs et al, 2018; laDue et al 2021). While numerous societal groups feel

118 concerned by surface water management, deep aquifer systems, are largely unknown to the public.
119 It is therefore less likely that political leaders will take up the issue and drive a consultative process.

120 The third challenge lies in the lack of a sense of interdependence between groundwater users. Due to
121 the spatial extension of the confined aquifer, its uncertain (and often complex) geometry, users of
122 deep confined aquifers do not necessarily know that they are part of the same hydrogeological
123 system. Unlike in river basins, where the link between upstream and downstream use is directly
124 observable, they may not perceive the physical reality of their interdependence. In addition,
125 stakeholders and users that should be involved in the management of large, deep and confined
126 aquifer systems have generally not had previous opportunities to collaborate, as water management
127 is typically organised along river basin boundaries, which rarely coincide with those of deep confined
128 aquifer. For all these reasons, they rarely have the feeling of belonging to a community of users.
129 Building such sense of belonging requires time, political will and resources – which may be lacking
130 (Duda, 2018; Molle and Lopez-Gunn, 2018) until stakeholders realize they share a common destiny
131 with respect to the groundwater resource.

132 The fourth challenge relates to the need to take a long-term perspective when engaging in
133 groundwater management. The evolution of groundwater status (especially in captive aquifers) is
134 often marked by great inertia. Aquifer recharge, transfer of pollutants, salt-water intrusion in coastal
135 areas, and land subsidence caused by overexploitation, are all phenomena that evolve slowly. Several
136 decades may pass before observing the effects of actions implemented today to protect the
137 resource. This lack of visible results in the short term, while the economic and political costs of action
138 are immediate, can represent a brake on the commitment of stakeholders.

139 The fifth and final challenge is that stakeholders often lack the required data, scientific skills and
140 tools (including models) to forecast the long term consequences of confined aquifer
141 mismanagement. This knowledge gap can lead to the expression of views challenging the
142 seriousness of the problem or its probability of occurrence. Such views may be based on the
143 existence of scientific controversies, it may aim to protect economic interests, or it may be the
144 expression of beliefs rather than scientific evidence (see Budds 2009 for an illustrative case in Chile).
145 As time passes, difficult decisions are postponed without stakeholders being fully aware of the cost
146 of inaction.

147 Given these numerous barriers, collective action to protect groundwater bodies, especially deep and
148 captive aquifers, has received less attention than for surface water bodies. In France for instance,
149 only 8 of the 181 local water management plans implemented or being developed focus on
150 groundwater (Rinaudo et al 2020). The next section revisits key determinants of collective action and
151 analyses how participatory scenario analysis can contribute to engage actors in groundwater
152 management.

153 **2.2. How can participatory scenario analysis help?**

154 Ostrom's (1990) landmark work has examined the determinants explaining enduring collective action
155 in natural resource management. Several of her cases focused on local groundwater management in
156 California (USA), building on her own work and later analysis by Bloomquist (1992). Two factors in
157 particular appear basic ingredients to initiate collective action. First, actors must agree on clear
158 boundaries on the resource, its characteristics and the web of actors exploiting and benefiting from
159 its exploitation. A rich literature has since examined these preconditions for local collective action on
160 groundwater (López-Gunn 2009; Rica et al 2012; Skurray 2015; Richard-Ferroudji and Lassaube
161 2020). These studies highlight the role of enhanced information on groundwater variability and
162 dynamics, careful identification of all potential users, and building a shared knowledge base.

163 Second, actors must find that the benefits of collective management outweigh the cost of not
164 working together; in other words actors must understand the risks of failing to implement jointly
165 agreed rules so as to agree to pay the transaction costs involved in starting collective action (Ostrom
166 1990). This requires creating an understanding of the interdependence between actors (Skurray
167 2015) and disproportionate cost of acting alone (Rica et al. 2012), as well as creating bonding and
168 bridging social capital formed through shared values and norms, and enhanced interconnections
169 (Lopez-Gunn 2012).

170 Participatory scenarios analysis provides a structured framework for initiating collective action.
171 Scenarios are narratives describing what the future might hold (Reed et al. 2013). Scenarios can
172 support actors in envisioning undesirable situations that everyone wishes to avoid, imagining more
173 desirable futures, and exploring possible transitions towards these futures. Scenarios do not aim to
174 predict or forecast the future. They describe internally coherent, contrasting developments that may
175 integrate break-up with current trends, leading to situations that can be very different from the
176 present or business as usual scenarios. Scenarios must be sufficiently different in order to foster
177 creativity between scenario workshop participants. Their main aim is not about finding the best
178 solution, but about providing a platform to reflect on the possible evolution of the social-ecological
179 system studied (Schneider and Rist 2013).

180 Scenario workshops can be used as a platform for social actors to construct new relationships or
181 enhance existing ones, encourage creative discussion on complex social-ecological systems dynamics
182 and build participants capacity in systematic and strategic thinking (Johnson et al. 2012). The focus
183 on long timescales (eg. what happens in 20+ years) can help create a disconnection with immediate
184 decisions to be taken and thereby reduce strategic behaviour because interests do not need to be
185 protected in the short term. The focus is on sharing knowledge, perspectives and worldviews in order
186 to expand one's mental model and encourage the creation of novel ideas to support decision-
187 making.

188 While it is illusory to imagine that politics can be removed, especially in controversial or conflictive
189 issues, scenario workshops can contribute to negotiations over the norms, rules and power relations
190 governing the use of natural resources (Schneider and Rist 2013). Hence, scenarios can contribute to
191 developing "transformation" knowledge by supporting the mapping out of pathways, strategies,
192 policies, programmes, and practices leading to desirable future.

193 Schneider and Rist (2013) argue that different types of scenario achieve different changes to actors'
194 knowledge. Normative scenarios, where each envisioned future maps against different tangible
195 goals, develop target knowledge (desirable goals). Explorative scenarios, where futures maps with
196 different dynamics, develop systemic knowledge on current conditions, the relationships between
197 system components and their possible evolution. In their study, Schneider and Rist (2013) first
198 developed normative scenarios then explorative scenarios on sustainable regional development and
199 related water governance.

200

201 **3. An application on a large regional, deep and captive aquifer in south west France**

202 **3.1. The Adour-Basin**

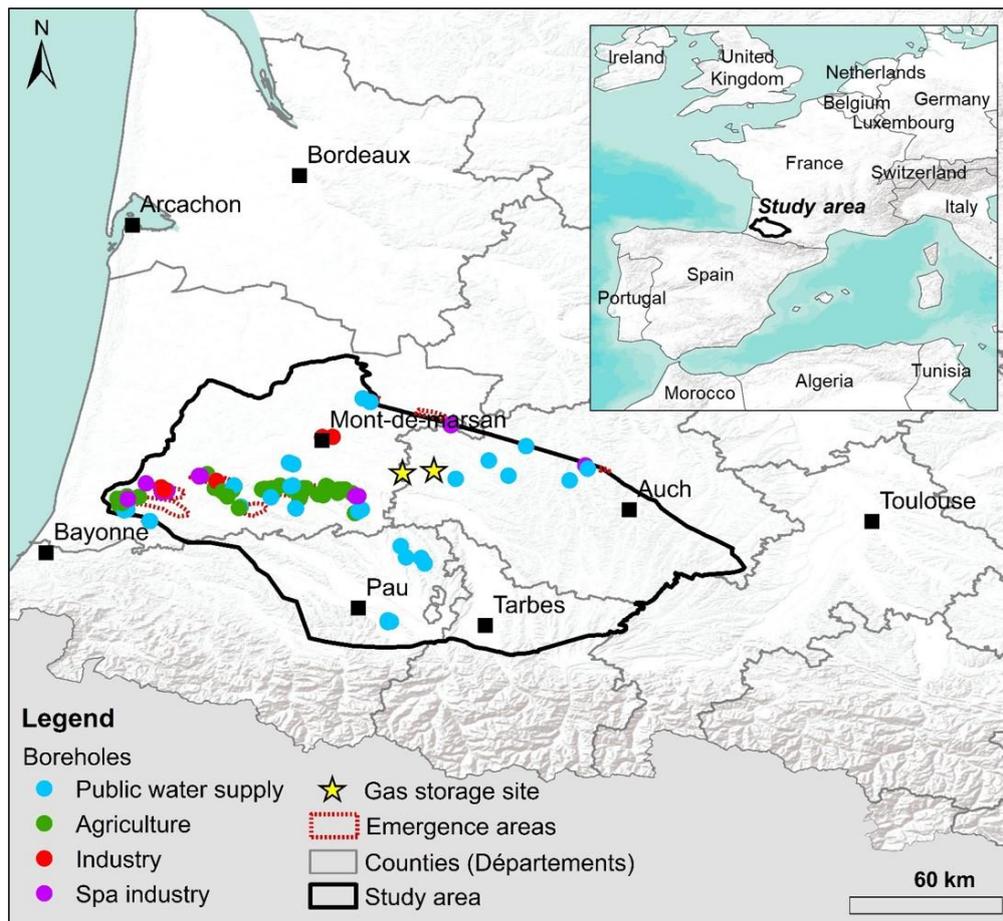
203 The regional deep confined aquifers under study are located in the Adour basin, in southwest France,
204 and extend across two regions and four counties (*départements*) (Figure 1). The groundwater
205 resource is a multilayer aquifer system situated in deep sedimentary layers formed during the

206 Cretaceous, the Paleocene and the Eocene. The most productive and most used of these aquifers is
207 the Sub-Molassic Sands (SMS) aquifer (Eocene layer) whose thousands-year-old water is of pristine
208 quality. The aquifer system, partly recharged in the foothills of the Pyrenees Mountains, is generally
209 located at a depth of several hundred meters, which protects it from surface pollution sources (see
210 also Douez, 2007; Wuilleumier, 2019; BRGM, 2021).

211 The sedimentary layers have undergone important geological deformations (faults, folds, etc.) with
212 the uplift of the mountain range 50 million years ago. Part of the complexity of the system is due to
213 this very disturbed geology, in particular:

- 214 • In certain locations, the deformations have brought the deep layers close to the surface
215 (emergence areas). Hence, in these areas the confined aquifers are vulnerable to percolation
216 of polluted water from surface land uses.
- 217 • In the Eocene layer, two deep anticlinal folds form bell-like structures with an impermeable
218 molassic ceiling. The gas industry uses these geological structures as storage sites. Gas is
219 injected in the anticline in summer (during low demand period) and recovered in winter
220 when energy demand increases. The two gas storage sites in the SMS aquifer are strategic to
221 France's gas supply; they represent 24% of the country's underground storage capacity
222 (Terega, 2021).
- 223 • The existence of faults enables the upwelling of high-quality warm water from the deep
224 aquifers, resulting in hot springs that have been exploited since Roman times and now
225 support an important spa industry.
- 226 • The different aquifer layers are not always isolated from each other. The SMS aquifer
227 interacts with the underlying Paleocene and Cretaceous aquifers, in areas where the layers
228 come into contact. The existence of water flows between the three aquifer layers implies
229 that the three should be managed together, increasing the complexity.

230



231

232 Fig. 1. Study area and boreholes pumping in the deep aquifers of South West France

233

234 **3.2. Key management issues**

235 This aquifer system has been increasingly exploited since the 1980s. Today, about 24 million cubic
 236 meters are abstracted yearly for drinking water supply (70% of total extraction), the spa industry
 237 (13%), agricultural use (11%), and industrial uses including bottled water and geothermal heating
 238 (6%). The deep aquifers are strategic for each of these uses in different ways (Neverre et al 2020):

- 239 • Drinking water extraction from the deep aquifers can be strategic for many communities, as
 240 surface sources are unreliable, due to pollution and drought risk. Overall, more than 70,000
 241 inhabitants are entirely dependent on the deep aquifers for public water supply.
- 242 • The spa industry represents an essential economic activity for local rural communities,
 243 bringing up to 90,500 clients every year, representing 1.5 million overnight stays, a total turn-
 244 over of 223 million € and creating about 3,200 direct and indirect jobs in the whole study
 245 area.
- 246 • Groundwater from the deep aquifers is also extracted for the irrigation of about 2000 ha of
 247 agricultural land, in areas where surface low flows in the dry season are severe.

248 The different users of the aquifers interact in many ways, causing several management issues:

- 249 • Due to increased pumping, piezometric levels of the SMS aquifer have dropped by 60 cm on
 250 average every year in the last 20 years, with no sign of stabilization despite a ban by the state
 251 on new borehole drilling. As a result, the SMS aquifer has been declared to be in bad

252 quantitative status under the EU Water Framework Directive. Reducing groundwater
253 extraction would be required to ensure its sustainability. A temporary ban on drilling was
254 imposed by the State in 2010 but use by existing wells is not regulated (no restrictions in
255 place) as such rules have to be developed together with users as part of a comprehensive
256 management plan (justification of the current study)

- 257 • The succession of gas injection (summer) and extraction (winter) from the storage sites
258 results in seasonal piezometric variations of up to 80 m and consequentially impacts
259 pumping installations of other uses in particular drinking water supply and the spa industry.
- 260 • In areas where the confined aquifers rise close to the surface, excess pumping and reduced
261 pressure in the aquifers may locally generate an inflow of poor quality water from polluted
262 overlying shallower aquifers and surface waters. A number of drinking water boreholes were
263 impacted (a number of which were abandoned) as well as the spa industry (forced to drill
264 deeper wells as existing ones were affected by contamination). Increasing pollutant
265 concentrations may require a relocation of wells away from emergence areas, or deeper
266 where water is of better quality but less accessible, if at all.

267

268 **3.3. Methodology**

269 **3.3.1. Rationale**

270 A number of sophisticated participatory scenario analysis methods were developed to co-construct
271 visions of possible developments (Van der Heijden et al 2002). Their major disadvantage is that they
272 require a high level of time involvement from the participants, which is impossible in the context of
273 confined aquifers (very limited initial interest of stakeholders).

274 The approach presented in this paper aims at solving that problem. It consists in developing narrative
275 scenarios based on information collected through bilateral interviews, and debating them in half-day
276 workshops (Rinaudo et al 2012; 2013). They are written in the form of fictitious press articles,
277 assuming that the use of narratives makes it easier for stakeholders to grasp the issues at stake and
278 to appropriate knowledge (Richter et al. 2009). "Man is an animal of stories" (Jouvenel 2004) and we
279 are most likely to engage actors in a participatory approach by taking a step away from the cold
280 scientific reality and moving towards fiction. In the approach described here, the scenarios blend
281 explorative and normative elements with the objective of developing system knowledge on the
282 dynamics of the confined aquifer, the interdependence of local actors extracting water and the
283 different response strategies to reduce extraction and protect the resource in the long term. Hence,
284 the scenarios usually include (i) some elements that reflect people's preference on futures and (ii)
285 the measures for reaching that future.

286 The semi-directive interviews with the actors in the area helped to formulate the main scenario
287 hypotheses. The main challenge lies in constructing scenarios that can be considered realistic by
288 participants, while incorporating enough transformative assumptions to force them to think "outside
289 the box". The time horizon of the scenarios must be far enough so that major structural changes
290 could take place.

291 Scenarios were debated with several objectives:

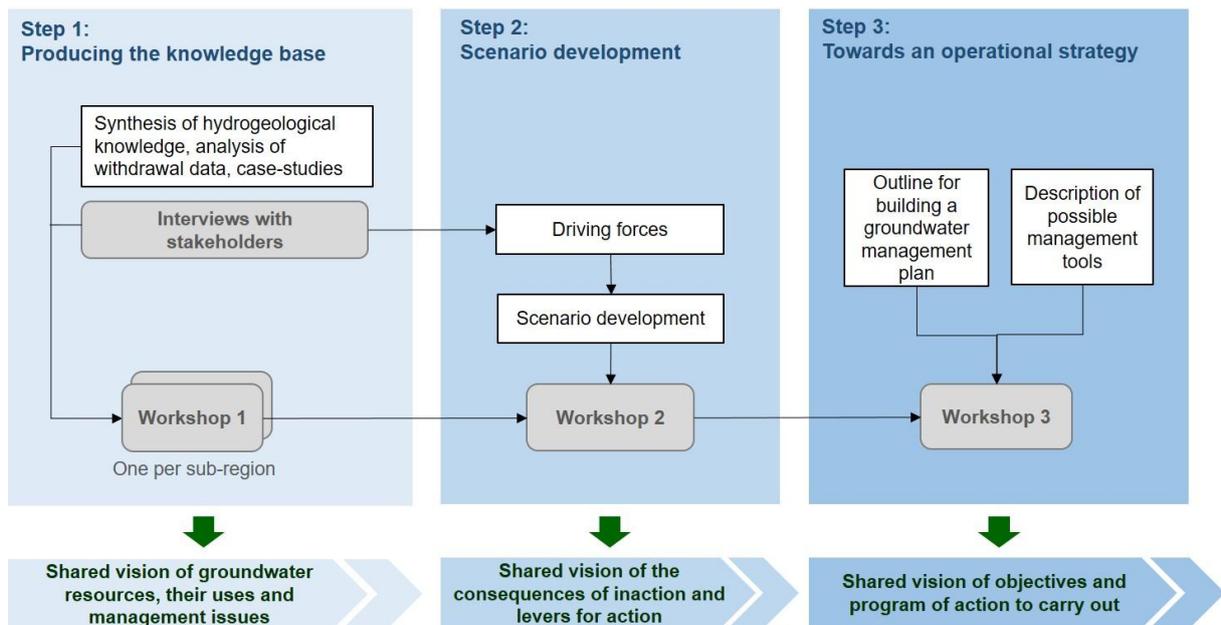
- 292 • To raise awareness among stakeholders of the possible consequences of inaction and the
293 power that participation gives them to influence the course of events.

- To create a sense of community: participants are allowed to venture into uncharted territory together, starting out on an equal footing in terms of their knowledge of groundwater. It facilitates the expression of deep and personal convictions (aspirations, values), as the distant time horizon makes it possible to distance oneself from institutional positions related to defending their immediate interests. In such way, the participatory scenario exercise allows for the creation of links between individuals who engage together in an exploration of the future.
- To demystify the complexity of the groundwater system and to give participants confidence in their ability to acquire the knowledge necessary for informed decision-making.

303

304 3.3.2. Implementation

305 The methodology was implemented in three steps, as shown in Figure 2. The first step involved a first
 306 workshop in which participants debated a synthesis of existing scientific and local knowledge on the
 307 hydrogeology of these aquifers, the economic significance of the aquifer for water uses, key
 308 management issues, potential management actions, key drivers of change, and expected
 309 evolutions in the next decade(s) (See Institution Adour, 2021). The aim was to raise actors’
 310 awareness of their interdependency via the deep aquifers.



311

312 Fig. 2. Overview of the three-stage approach

313

314 The actors involved in the bilateral interviews and invited to the workshop were selected based on
 315 their likelihood to be involved in future management, planning and governance of the resource, as
 316 prescribed in French water policy rules related to the development of Water Management Plans (for
 317 more details see Rinaudo et al 2020). The study focused on users of the deep aquifers, including
 318 public drinking water utilities, the gas storage public company, the spa industry, agricultural and
 319 industrial sectors, and state agencies (Table 1). Individuals involved were mainly technicians and
 320 utility managers, as well as locally elected politicians.

321

323

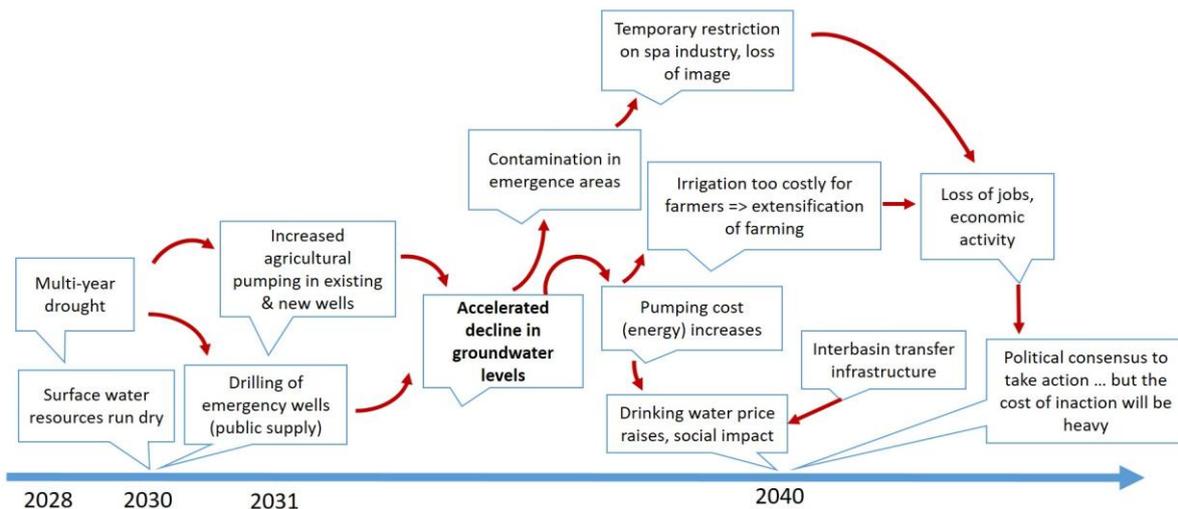
324 **Table 1. Number of stakeholders from the different sectors engaged in the participatory approach**

Sector	Interviews (April-December 2018)	Workshop 1 (December 2018)	Workshop 2 (April 2019)	Workshop 3 (October 2019)
Public water supply utilities (engineers & elected board members)	4	11	11	9
Agriculture (professional organisations, associations of water agricultural users)	6	4	2	2
Spa industry (private group)	1	2	3	3
Geothermal energy	2	1	2	1
Gas storage company (Terega)	1	1	-	1
Adour river basin management authority (AEAG)	1	3	3	3
County councils (<i>départements</i>): engineers & elected council members)	2	2	1	6
Adour Garonne River basin District Agency	1	1	1	3
Environmental Regional Government Agency (DREAL)	-	-	2	1
Health Regional Government Agency (ARS)	-	-	1	-
Government agency in charge of land-use planning (DDTM)	-	-	1	-
Total	18	25	27	29

325

326 The second step involved a second workshop in which two narrative scenarios of the future were
327 developed and debated. The first related to a baseline scenario where no action is taken ("*laisser-*
328 *faire*") with a 2040 timeline, which was coherent with the observed trends and deemed near enough
329 to be relevant for management planning. The "*laisser-faire*" scenario was presented in the form of
330 three fictional press releases, for which the story is summarized in Figure 3.

331



332

333 Fig. 3. Main assumptions of the “laissez-faire” scenario

334

335 The newspaper fictional articles (see Neverre et al 2020) take the reader into a situation of multi-year
 336 drought which dries up or affects the quality of most surface resources, leading to the urgent
 337 creation of deep wells. Where deep aquifers are more accessible, agricultural users also rely on these
 338 aquifers to increase their security of supply. While the deep aquifers save the region from drought in
 339 the short term, the increase in withdrawals precipitates the drop in piezometric water levels. Ten
 340 years later, the pumps of many boreholes risk being dewatered, thermal resources are affected,
 341 leading to the temporary closure of some spa resorts, and gas storage activities are compromised. In
 342 that narrative scenario, elected representatives finally call for action in 2040, although part of the
 343 damage has already taken place.

344 A second scenario was then debated, in which decision makers would have been more pro-active.
 345 The scenario was presented as a fictitious roadmap comprising of several measures to regulate
 346 withdrawals and protect the aquifers from surface pollution (Figure 4). The measures are described
 347 in detail to enable participants to understand the regulatory, economic and institutional levers that
 348 can be used to influence the course of events. They are implemented from 2030.

349

PILAR 1	PILAR 2	PILAR 3
<p>GW is an insurance against drought</p> <ul style="list-style-type: none"> • Priority to drinking water & the spa industry (agricultural boreholes are closed by 2040) • Water conservation programs implemented in the drinking water sector & spa industry • Reduction in groundwater pumping when superficial water is available (even if treatment is more costly) – confined aquifer kept for drought periods only • Development of a grid to facilitate conjunctive use of surface / groundwater • Cost sharing at regional level, including gaz storage company 	<p>Definition of sustainable extraction</p> <ul style="list-style-type: none"> • Groundwater threshold target set for 2070 • Maximum groundwater level decline agreed (in cm/ year), with use restrictions if target not met • Extraction limit defined in volume (per year), based on modelling 	<p>Protection of water quality</p> <ul style="list-style-type: none"> • Protection zones are defined in emergence areas; restrictions in terms of pesticide use • Groundwater threshold levels are defined; pumping is restricted if those levels are breached • Extraction limits are set as annual volume for each protection zone / each well • New agricultural wells authorized if no use of pesticides

350

351 Fig. 4. Fictitious groundwater management plan presented to trigger discussions in workshop 2

352

353 The third step involved a third workshop aimed to generate discussions on the institutional set-up
 354 that could be used to support the implementation of a collaborative governance. Three main
 355 institutional frames were presented and discussed (Table 2). The workshop involved participants
 356 from Step 2 and as well as other actors who could not participate in the previous workshops but
 357 decided to participate in the following workshops. A pre-workshop was also organised with local
 358 politicians to give them an overview of the project and its outcomes following the first two sets of
 359 workshops.

360 **Table 2. Proposed institutional set-ups**

Name	Description
Charter	Voluntary commitment to implement good practices in terms of water use efficiency, data sharing, transparency on extractions
Contract	Voluntary participation to a programme of actions (corresponding to the three pillars presented in Figure 4), with public subsidies
Water Management Plan	Establishment of a Water Commission in charge of developing a legally binding groundwater management plans

361

362 The workshops involved a mix of presentations from the project team, discussion rounds (including
 363 systematic roundtable to ensure all participants could express their opinion) and responding to short
 364 questionnaires to collect additional written evidence from all participants on a number of key issues.
 365 It is important to note that the project was funded in the context of a wider research initiative aiming
 366 at understanding the complex hydrogeology of the region. The project team facilitating the
 367 workshops consisted of an interdisciplinary team of scientists working for the French Geological
 368 Survey. It was clear to participants that the scope of the project was exploratory.

369

370 **4. Results**

371 Although the methodology was designed for a progressive consideration of issues (from an
372 understanding of the current situation, the consequences of *laisser-faire* and potential responses),
373 local actors often discussed elements of all three issues in all workshops. Therefore, it was decided to
374 present the results of the participatory processes according to five outcomes, presented below.

375 **4.1. Developing a shared representation of the resource and its uses**

376 Most participants were representative of groundwater users (agriculture, spa industry, public water
377 supply, see Table 1) and came to the workshops bringing their own mental model or conceptual
378 representation of the groundwater resources. These mental models were based on local knowledge
379 related to the operation of boreholes (direct observations, site-specific studies). Users were aware of
380 the existence of the aquifer, its depth, productivity, the quality of water contained in the deep layers
381 and the existence of a declining trend in water levels. However, only a few participants could fit this
382 local knowledge into a more general representation of the aquifer system. The workshops were
383 therefore useful for all users to understand the larger picture, including the spatial extension of the
384 aquifers, the existence of water flows between different layers and the interdependences between
385 water users.

386 Local knowledge provided by users was clearly perceived as complementary to the scientific
387 information provided by the project team, which contributed to the collective appropriation of the
388 information and the emergence of a shared representation of the groundwater resources. Lay
389 participants, such as elected politicians, who came without pre-existing groundwater mental models,
390 adopted the conceptual representation of the aquifer proposed by the research team, probably
391 because it was in line with the local knowledge of the other (more technical) participants.

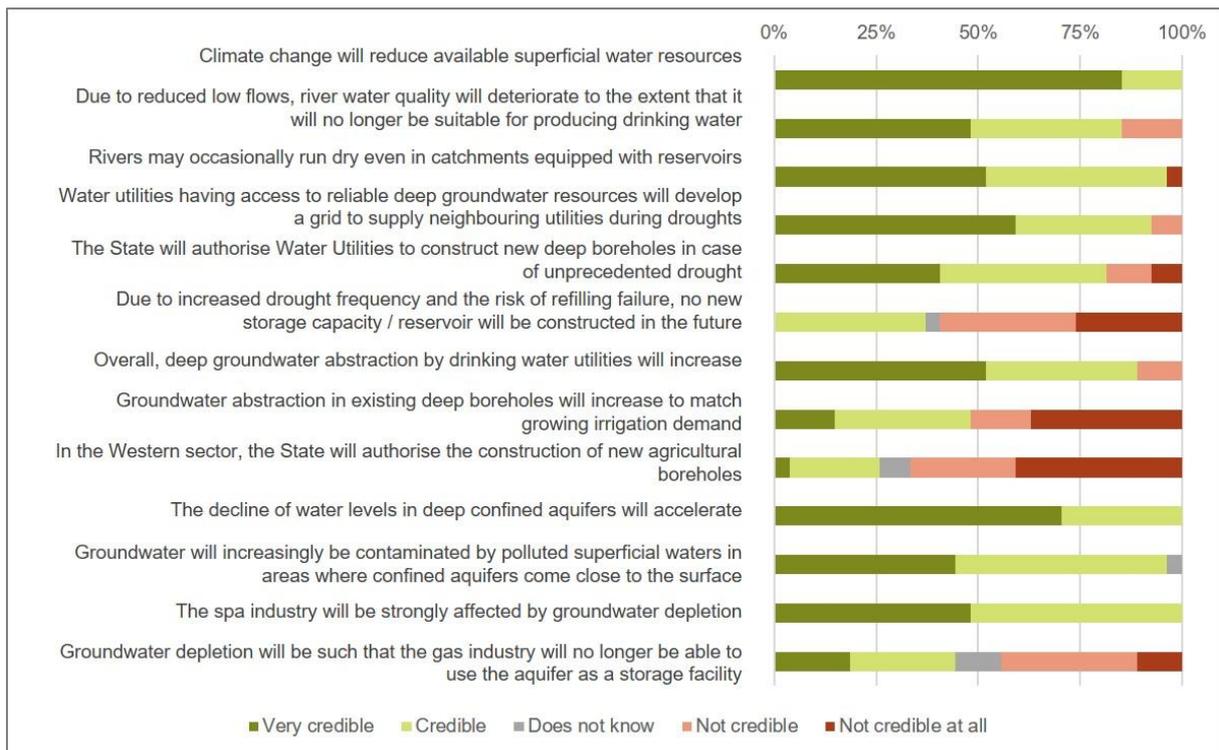
392 The identification of groundwater management issues was also consensual, given that users
393 participating to the workshops could provide first hand evidence of the problems caused by
394 groundwater depletion or quality deterioration, confirming data provided by the research team.

395 Overall, several factors have contributed to the relatively rapid emergence of a shared vision of the
396 deep groundwater resources, uses and management issues. First, the project team was considered as
397 scientifically legitimate, as several experts involved were in charge of a research program on deep
398 confined aquifers at the regional level. Second, technical and scientific experts from other
399 institutions were invited, who could potentially contradict or complement the information provided
400 by the project team. Third, local stakeholders could contribute to the discussion by bringing local
401 knowledge. Importantly, the project team was transparent about sources of uncertainties, in
402 particular related to groundwater recharge and interactions between aquifer layers.

403 **4.2. Raising awareness of the benefits of collective action**

404 One of the main objectives of the workshops was to raise awareness among stakeholders of the risks
405 of inaction. This was achieved during Workshop 2 through the discussion of the *laisser-faire* scenario
406 describing the potential consequences of a lack of integrated groundwater management at the 2050
407 horizon. Overall, participants considered the *laisser-faire* scenario realistic. Several participants even
408 considered that the situation depicted in the narrative description would probably occur much
409 earlier. A questionnaire filled out during Workshop 3 helped further identify assumptions that were
410 considered more or less credible than others (Figure 5).

411



412

413 Fig. 5. Perception of the main assumptions formulated in the narrative description of the *laisser-faire*
 414 scenario (Workshop 2, N= 27 respondents)

415

416 Discussions helped construct a first representation of the causal link between driving factors likely to
 417 accentuate groundwater depletion and the consequences of the deterioration of the resource. Most
 418 driving factors included in the narrative were confirmed and illustrated. For instance, several actors
 419 gave precise examples of urban areas which were already contemplating the possibility of drilling
 420 new boreholes to secure their water supply, currently dependent on fragile surface resources.

421 A limited number of assumptions were also questioned or contested during discussions. For instance,
 422 many participants, in particular agricultural representatives, refused to take for granted the
 423 assumption that no new surface water reservoirs could be constructed in the future. They asked for
 424 scientific evidence of a key assumption made in the narrative scenario, i.e. that those reservoirs
 425 could not be filled under future climate conditions.

426 Given the general credibility of the *laisser-faire* scenario and some of its key assumptions, a
 427 consensus emerged on the need to take action to prevent this *laisser-faire* scenario from happening.
 428 There was clearly a shared understanding that significant costs could be avoided, benefiting to all
 429 users.

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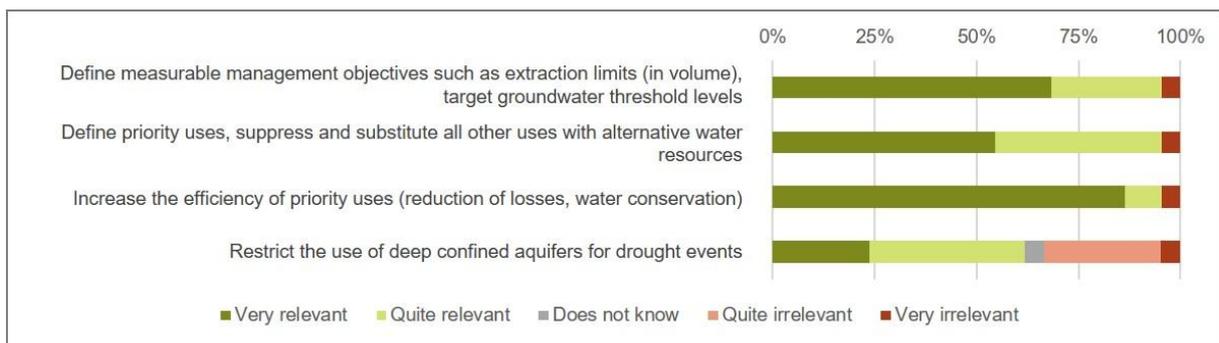
433 4.3. Defining management principles and operational actions

434 The next result obtained was the definition of objectives that would guide the definition of concrete
 435 groundwater management measures. There was a clear consensus among participants that the

436 resource should be protected from depletion and pollution in order to ensure its possible use for
 437 future generations. The fact that the pristine water contained in deep confined aquifers is several
 438 thousand years old contributed to this consensus because the resource was considered as a natural
 439 heritage to be used wisely. The identification of such shared ethical and philosophical values appear
 440 important to create shared foundations for future collective action.

441 Users agreed on several key management principles during Workshop 3 (Figure 6). First, they agreed
 442 on the need to define measurable management objectives, such as for instance extraction limits (in
 443 volume) and the definition of groundwater threshold levels that should not be breached. Second, all
 444 agreed that water from the aquifers should be used for drinking water supply as a priority and, to a
 445 lesser extent, by the spa industry, considering its economic importance at regional level. Uses that do
 446 not require a high quality water should be reduced, and if possible satisfied with other sources. This
 447 applies primarily to agricultural uses, and implies shutting down and substituting agricultural
 448 boreholes where other water resources are available (or reducing irrigation). This substitution
 449 principle should also apply to some urban uses, such as the watering of green spaces or fire hydrants,
 450 where technically and financially feasible. Third, losses in distribution networks should be reduced
 451 and water use efficiency improved (e.g. households' per capita consumption, water saving
 452 technologies in commercial, industrial and institutional uses).

453



454

455 Fig. 6. Evaluation of proposed management principles for managing dropping water levels in the SMS
 456 aquifer by workshop participants (Workshop 3, N= 22 respondents)

457

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460

461 The emergence of a consensus on those principles was somewhat surprising because their
 462 implementation would imply significant efforts and costs to some stakeholders. Some users, for
 463 instance farmers, could have claimed their legitimacy to continue using water based on seniority in
 464 use. Farmers' representatives nevertheless agreed that such high quality (and old) water should not
 465 be used to irrigate crops.

466 The authors observed two points that moderate the consensus found on management principles.
 467 First, although farmers agreed on the priorities that should apply to uses extracting water from the
 468 deep aquifers, they were against any extraction ban unless alternative sources of supply were
 469 developed. However, alternative sources of water are not readily available today. Developing new
 470 reservoirs is not always possible because of stringent regulatory, environmental, socio-political and

471 economic constraints. Second, diverse views were expressed concerning the proposal to restrict the
472 use of the aquifers only to periods of drought, when alternative resources are scarce, as this would
473 require extensive reorganisation for users and infrastructure (grid) who are currently depending on
474 this resource. Both observations indicate that, while users can find common management principles,
475 issues of cost allocation remain central (Girard et al 2016).

476 Furthermore, moving from management principles to measurable objectives was not possible. A
477 number of formulations were proposed as a starting point for the discussion on management
478 objectives. Alternative formulations relating to groundwater-level objectives included for example: (i)
479 ensure a stabilisation of groundwater at current piezometric levels; (ii) ensure that groundwater
480 levels do not decline by more than 0.5 meter per year; (iii) ensure that the piezometric surface
481 remains above the critical level that is required for underground gas storage. Formulations relating to
482 abstraction-level objectives were also suggested: (i) setting a fixed annual cap for total water
483 abstraction from the deep aquifers; (ii) setting an average cap that can be exceeded if needed during
484 a particularly dry year, provided that the 5-year average remains below cap. Such measurable
485 objectives could be set for different time horizons or for different areas. However, participants
486 considered that there was a lack of scientific information to discuss those proposals. Participants
487 expressed the need for using a groundwater model to choose between these different formulations,
488 based on simulation results. In particular, participants stressed the need to evaluate the maximum
489 volume that should be abstracted to stabilize water levels. Clearly, more knowledge was needed to
490 characterize the relationship between extraction and the evolution of groundwater level over time.

491 Although measurable management objectives could not immediately be defined, participants agreed
492 that a number of no-regret actions could be initiated while waiting for additional knowledge. It
493 consists of all actions that will be necessary and useful whatever the precise definition of measurable
494 management objectives: all water saving actions and actions to reduce the risk of contamination of
495 deep aquifers. Most of the discussions focussed on how the financial burden should be shared. The
496 dominant opinion was that all users of water resources of the aquifers and overland surface water
497 bodies should contribute, whether or not they currently used the deep aquifers. Indeed, the
498 participants agreed that it would not be fair to impose the cost of the protection of the aquifers only
499 to their current users, since the resource represents an asset for all future inhabitants of the area.
500 There was little contradictory opinion expressed in the room, possibly because participants were
501 mainly users of these aquifers.

502

503 **4.4. Mapping governance options**

504 One of the outcomes of the workshop was the identification of a number of general governance
505 principles. First, users agreed that they should collectively act and that the regional level (including
506 the whole study area) was the appropriate scale due to the interdependency between existing and
507 potential users of the deep aquifers, and those of surface water resources. Second, there is a need to
508 develop a groundwater management plan specifying mid-term objectives (5 years) as well as a set of
509 operational actions. Third, users believed that the State should supervise that process in order to
510 ensure commitment from various stakeholders and to guarantee that management actions are
511 consistent, efficient and based on a fair distribution of effort.

512 Four institutional instruments were proposed and discussed by stakeholders during the last
513 workshop. Their characteristics are briefly described in Table 3. Overall, there was agreement that, in
514 the short term, an initial commitment to collective action could be made more concrete via the
515 signature of a “*memorandum of understanding*”, which is currently being adopted (see section

516 'Evaluation of outcomes'). This would provide a first political impetus to give direction and a common
 517 agenda to practitioners. In the medium term, contractual instruments together with funding could be
 518 used to encourage collaboration. In the longer term, the deep aquifers would benefit from a
 519 common and more ambitious management plan that would coordinate more systematically
 520 management actions by individual actors.

521

522 **Table 3. Main characteristics of the four institutional set-ups proposed to workshop participants**

Institutional set up	Charter of good practice	Aquifer contract	Territorial project	Integrated Management Plan
Objective	Signal commitment to act by signatories and define action principles	Fund a program of work	Define a water allocation plan & long-term vision of water use	Design a long legally binding long-term plan
Content				
- Deals with issues related to:	Specific to charter	Specific to contract	Quantity (mainly)	All water management issues
- Performs a diagnosis of the situation	No	Yes	Yes	Yes
- Funds operational actions	No	Yes	Yes	Yes
- Defines legally binding objectives (e.g. sustainable extraction limits)	No	No	Partially	Yes
- Provides a long term vision of water management	No	No	No	Yes
Stakeholders involved				
- Funding agencies	No	Yes	Yes	Yes
- Regulatory Agencies	No	No	Yes	Yes
- River / aquifer managers	Yes	Yes	Yes	Yes
- Water users' representatives	Yes	No	Yes	Yes
Life cycle	No duration, one shot	3 years, one shot	5 years, one shot	5-10 years, updated regularly

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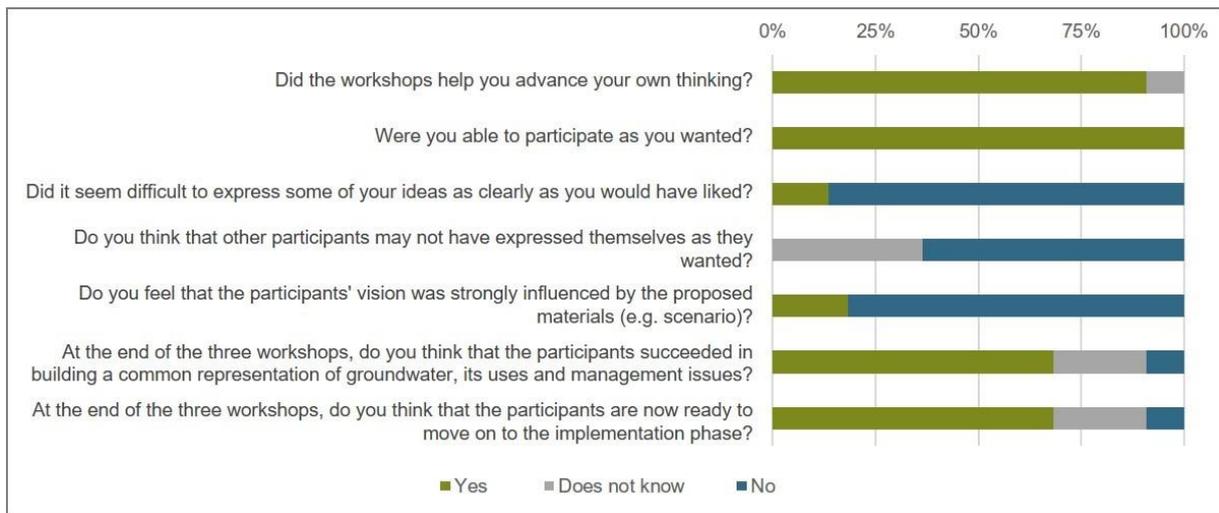
525 **4.5. Evaluation of outcomes**

526 An evaluation survey was filled out by participants at the end of the last workshop. 91% of
 527 participants indicated that the participatory process advanced their own thinking (Figure 7). A
 528 majority (68%) also stated that the process succeeded in building a common representation of the
 529 aquifer systems and in creating a favourable ground to move to the implementation phase.

530 Furthermore, the collective dynamic initiated by the approach did not stop at the end of the last
 531 workshop. Stakeholders are currently making their commitment to collective action more concretely
 532 via the signature of a "Charter of commitment for the governance and concerted, sustainable and
 533 solidary management of the deep aquifers of the Adour basin". By June 2021, this charter had been

534 signed by 16 members, including the Water Agency and other water management authorities,
 535 governments at regional, county (*Départements*) and local (*Communautés de communes*) level,
 536 Chambre d’Agriculture des Landes, several public water utilities, the gas storage company, and a spa
 537 company ; the signature process was underway for several other signatories. The Charter explicitly
 538 references and follows on from the participatory approach and its first objective is stated as “to
 539 formalize the commitment of stakeholders to continue the dynamic initiated since 2018”. By signing
 540 the charter, members commit to participate in the governance and reflections on the management
 541 of the deep aquifers, with the aim of putting in place a more formal management set-up, and to start
 542 implementing adapted policies and no-regret actions (in particular water savings and water quality
 543 preservation).

544



545

546 Fig. 7. Evaluation of the methodology and its outcome by participants (Workshop 3, N = 22
 547 respondents)

548

549

550 5. Discussion

551 The paper presented a methodological approach to initiate collective action for the management of a
 552 deep, large and confined aquifer, and tested it in the context of an intensively exploited aquifer of
 553 France. France has well-established institutions for the management of river basins (Jager et al 2016)
 554 and a strong regulatory context for groundwater protection thanks to the EU Water Framework
 555 Directive goals to achieve good quantitative and chemical status in all European groundwater bodies.
 556 However, as elsewhere in the world, the fate of confined and deep aquifers has often been
 557 overlooked, and a lack of interest and engagement from stakeholders and users hindered the needed
 558 momentum and political will to implement integrated groundwater management (Rinaudo 2020).
 559 The objective of this research was thus to test whether and how participatory scenario analysis and
 560 future thinking could generate awareness and a commitment to initiate collective action for the
 561 integrated management of a regional, deep and confined aquifer.

562 Overall, results indicate that participatory scenario analysis has helped generate two ingredients for
 563 collective action: improving actors’ understanding of their interdependence and the benefits in
 564 taking collective action (Ostrom 1990). The methodology has improved some of the main challenges

565 when raising stakeholder's awareness of groundwater issues: making them more "visible" (Lopez-
566 Gunn 2009) and enhancing actors' ability to think systematically or holistically on their integrated
567 management (Johnson et al. 2012). Opinions expressed during the final roundtables and the final
568 survey (see section 'Evaluation of outcomes') suggest a greater understanding of the complex and
569 multiple interactions between extraction activities and pollution pressures across the region. In
570 addition, the methodology has increased awareness of the cost of inaction and improved the
571 perception by users of the severity of the problem. These factors are commonly identified as
572 catalysts for collective action (e.g. Lubell et al 2002; Rica et al 2012).

573 There is also evidence that transformative knowledge was created (Schneider and Rist 2013). During
574 workshops, actors identified a number of implementable measures and expressed the willingness to
575 commit to more collective management of the aquifers during the workshops. Since then, key public
576 actors and stakeholders are in the process of signing the charter of commitment for the sustainable
577 and integrated management of the deep aquifers. These outcomes are not tangible environmental
578 improvements and do not present a specific programme of action, arguably two desirable outcomes
579 of participatory processes (e.g. Newig et al 2018). Yet, the objective set out by the project (i.e. to
580 initiate collective action) was met, with, importantly, concrete commitments made at a political level
581 to engage in further groundwater management planning, when no attention or interest to the issue
582 was shown previous to the workshops.

583 What are the key features of the methodology that may explain these positive outcomes, and when
584 should it be used for wider implementation? Three key dimensions are discussed here: 1) how the
585 methodology approached stakeholder fatigue, 2) how it integrated local knowledge, and 3) how it
586 made groundwater more "visible".

587 First, French water management relies already heavily on collaborative work (eg. for catchment
588 planning, river basin management, development of climate change adaptation plan, etc.), while the
589 number of water actors is small. Moreover, many key individual actors from local government are
590 simultaneously solicited by many other public policy participatory design processes. Hence,
591 stakeholder fatigue is a significant challenge in French water management. In participatory scenario
592 approaches, a trade-off exists between asking participants to react to pre-defined scenarios or asking
593 them to co-create scenarios. Scenarios may be co-created to reduce expert bias in scenario
594 development and adequately integrate stakeholder knowledge, views and preferences (Schneider
595 and Rist 2013). However, such level of co-creation requires significant involvement from
596 stakeholders, as each variable must be defined, weighted and integrated into coherent narratives.
597 This increases the risk of stakeholder fatigue.

598 The methodology presented in this paper thus opted for participatory scenario analysis, structured
599 around a rapid appraisal through one-to-one interviews and short workshops where participants
600 discuss a small number of pre-defined scenarios. The positive outcomes of the study support the
601 conclusion of Reed al (2018) who rejected the "*normative assertions that engagement should always*
602 *be as far up the ladder as possible, to use Arnstein's ladder analogy*" and, instead, argued that "*all*
603 *types of engagement should be available to use*", based on the "*understanding of what works*"
604 (according to the analogy of a "wheel of participation"). In this case study, participatory scenario
605 analysis proved to be efficient in exploring the complexity of the system, the drivers determining its
606 evolution, possible transformations and their consequences, as well as the levers for action. It gave
607 meaning to engage in further participation and build a commitment for further collective action on
608 managing the deep aquifers.

609 Second, mixing scientific and local knowledge is a recommendation found in much research on
610 participatory processes (e.g. Blackmore 2007; Reed et al 2008; 2018; Simpson and De Loe 2019). In
611 this research, the integration of local knowledge was an essential element of the approach taken by
612 the scientific team. The development of the regional aquifer model relied on data, results and
613 hydrogeological models from public authorities and stakeholders. The preparation of scenarios relied
614 equally on general statistics as on information provided by, and views from, these local actors. This
615 approach resulted in a more robust and shared understanding of the social-ecological system.

616 In addition, the scenarios were developed to *“match the representation of stakeholder interests and*
617 *decision-making power to the spatial scale of the issues being considered”* (Reed et al. 2018). A step-
618 wise process was adopted, first by involving key technicians and practitioners working at county or
619 regional level for public authorities and user groups. This allowed providing a more shared
620 understanding at a technical level when moving to the political arena by involving elected
621 representatives from county and regional authorities and user groups. This stepwise approach to
622 supporting changes in environmental management is coherent with lessons learned from policy
623 studies examining paradigmatic policy change, for instance in flood risk management (Johnson et al.
624 2005) or river basin management (Huitema et al 2014).

625 Third, to address the issue of making groundwater “visible”, much time was spent on the visual
626 representations of the geology of the aquifers, and finding the right analogies and local examples to
627 explain hydrogeological dynamics. The hydrogeologists involved in the project had a pivotal role in
628 workshops in explaining the underpinning science, in particular to politicians who initially expressed
629 reluctance in engaging in the participatory process by fear of lacking the scientific background. The
630 presentation of the scenarios and their possible consequences through concrete illustrations was a
631 critical step. It was particularly valuable to draw on the interviews to make the scenarios most
632 relevant to the local context. The time spent in communicating scientific knowledge proved essential
633 to generate the level of shared understanding and commitment needed for further collective action.

634 Overall, the design features that contributed to its success in initiating collective action with respect
635 to the deep aquifers also limit the broader applicability of the methodology. Indeed, the
636 methodology limited on purpose the number and type of participants to those with responsibilities
637 over the management of the deep aquifers (e.g. public authorities) and those with most economic
638 interest in their exploitation. Furthermore, it limited the time spent on workshops. Hence, it does not
639 aim to include all possible viewpoints and interests on the management of the aquifers and it does
640 not aim to create the full range of possible scenario for their management. More formal,
641 comprehensive and inclusive processes would be needed to ensure the robustness and acceptability
642 of the final operational goals, targets and measures of an integrated plan of the deep aquifers. Thus,
643 the methodology is valuable for its role in building a shared understanding of the need for an
644 integrated management of the deep and confined aquifers, and the justification for initiating
645 collection action at a technical and political level.

646

647 6. Conclusion

648 With rapid environmental change and a growing groundwater crisis, mobilising actors in reversing
649 declining water levels and pollution of aquifers is an urgent task in many regions of the world. Work
650 on effective tools and methods to initiate and strengthen collective action are thus essential in any
651 attempts to reach sustainability. In particular, there is a need to further develop socio-hydrogeology
652 (Sivapalan et al 2011) and integrate social sciences into the assessment and management of
653 groundwater resources (Barthel et al 2017). This paper shows that participatory scenario analysis can

654 make deep, confined aquifers more “visible” to societal actors and contribute to create a shared
655 understanding of the need to adopt more integrated management. The study also shows that
656 participatory scenario analysis can be enough to generate a commitment for collective action on
657 their management, mitigating the issues of stakeholder fatigue that deliberative democracy can
658 create. Overall, the method presented in this paper provides an original contribution to the field of
659 socio-hydrogeology, by combining the integration of social and hydrogeological perspectives into
660 participatory scenario analysis for the management of deep and confined aquifers.

661

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664

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670

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