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Guillaume Bertrand, Paul Cary, Lise Cary, Ricardo Hirata, Emmanuelle Petelet-Giraud, Marc Steinmann, Victor Coelho, Suzana Montenegro, Anderson Paiva, Cristiano Almeida

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1 **Socio-environmental monitoring and co-management strategies to favor**  
2 **groundwater recharge and sustainable use in southern metropolises: toward a**  
3 **co-Managed Aquifer Recharge model?**

4 <sup>a</sup>Guillaume Bertrand, <sup>b</sup>Paul Cary, <sup>c</sup>Lise Cary, <sup>d</sup>Ricardo Hirata, <sup>e</sup>Emmanuelle Petelet-Giraud, <sup>a</sup>Marc  
5 Steinmann, <sup>e</sup>Victor Coelho, <sup>f</sup>Suzana Montenegro, <sup>f</sup>Anderson Paiva, <sup>g</sup>Cristiano Almeida

6 <sup>a</sup>University of Bourgogne Franche-Comté, UMR 6249 UFC CNRS Chrono-Environnement, 4 place Tharradin,  
7 Montbéliard ;16 route de Gray, Besançon, France

8 <sup>b</sup>University of Lille, ULR 3589 - CeRIES - Centre de recherche « Individus Épreuves Sociétés », F-59000 Lille,  
9 France

10 <sup>c</sup>BRGM, French Geological Survey, 3 Av. C. Guillemin, 45060 Orléans, France

11 <sup>d</sup>University of São Paulo, CEPAS, Institute of Geosciences, 05508-080 São Paulo, Brazil

12 <sup>e</sup>Federal University of Paraíba, Department of Geosciences, João Pessoa, PB 58051-900, Brazil

13 <sup>f</sup>Federal University of Pernambuco, Civil Engineering Department, UFPE, 50740 Recife, Brazil

14 <sup>g</sup>Federal University of Paraíba, Water Resources and Environmental Engineering Laboratory, João Pessoa, PB  
15 58051-900, Brazil

16

17 **Abstract**

18 In rapidly growing Southern metropolises, climatic, anthropogenic and demographic pressures,  
19 combined with centralized network deficiencies, favor individual initiatives to access freshwater *e.g.*,  
20 illegal well settlements, pirate connection to the distribution network, rain harvesting and storage in  
21 tanks. These strategies are amplified by extreme meteorological events (*e.g.*, droughts) that also  
22 trigger cognitive mechanisms, such as denial, opportunism or a kind of “myopic” competition to  
23 access the resource without considering (knowing) collateral impacts. From these environmental and

24 social dimensions, this review first evaluates the arguments for the integration of Managed Aquifer  
25 Recharge (MAR) in socio-environmental observatories (SEO). SEO are structures concurrently  
26 monitoring natural, anthropogenic, and engineered processes but also relationships between  
27 stakeholders/managers and end-users. Second, in order to take advantage from the current private  
28 (and illegal) strategies, MAR implementation accompanied with a SEO structure is discussed to show  
29 how it promotes cognitive, social, economic, and governance conditions required for successful co-  
30 management.

31 **Keywords:** Contamination; Water resource management; Critical Zone; Aquifer Storage and  
32 Recovery; Common-Pool Resources

33

#### 34 **Introduction: Multidimensional patterns of water resources and Managed Aquifer Recharge (MAR)** 35 **interests in Southern densely populated areas**

36 By 2050, the population living in urban areas will reach 68 % of the global population (9,7  
37 billions), with up to 90% of this increase concentrated in Asia, Africa, and Latin America, where urban  
38 areas reach great population densities due to compact urbanization schemes [1] [2] [3]. In such hot-  
39 spots of climatic, demographic, and anthropogenic pressures, groundwater recharge is threatened by  
40 soil impermeabilization, combined with heat island effects, further amplified by extreme events  
41 (droughts/floods) combined with fragmentation/disappearance of green areas [4] [5]. Concurrently,  
42 groundwater pumping is known to enhance groundwater pollution and saline intrusion risks for  
43 coastal cities [6] [7] [8] [9]. Therefore, major management plans are required to mitigate the impact  
44 of these changes on water supply in southern metropolises [10]. This makes Integrated River Basin  
45 Management and the so-called Integrated Urban Water Management (IUWM) very challenging,  
46 given that it must “promote the coordinated development and management of water, land and  
47 related resources, in order to maximize the resultant economic and social welfare equitably without  
48 compromising the sustainability of vital ecosystems” [11]. This implies that IUWM policies should

49 account for both intrinsic (hydrological and biogeochemical aquifer functions) and extrinsic (climate  
50 change, overexploitation, network management, contamination, and salinization) control  
51 parameters, and articulate the “little water cycle” (i.e., the urban water cycle) with the “great water  
52 cycle” occurring at the regional (catchment) scale. In addition, IUWM also requires to integrate  
53 complex management strategies distributed throughout multilayer governance structures (from  
54 municipality to supra-national scales) as well as the multilayer social dimension of consumers [12]  
55 (Figure 1). Such a nested multi-level dimension is challenging to be addressed by geoscientists,  
56 researchers in human sciences, and water managers, and raises the need for tight co-investigations  
57 and collaborations between these communities [13].

58 Over the short term, a possible way to (unsustainably) secure the human demand is to limit  
59 water consumption by ecosystems, which is often unintentionally accomplished by the increasing  
60 urbanized land use. In Southern countries featuring tropical and semi-arid climate, various studies  
61 demonstrated that deforestation and the reduction of crop surfaces first lead to the increasing  
62 availability of living space and water for human purposes [14]. Nevertheless, deforestation  
63 deteriorates in most cases the quality of the groundwater resource, leading to higher costs for  
64 drinking water treatment. This imposes a severe constraint to the installation and maintenance of  
65 water supply systems, in particular for local communities [15] with often lacking or deficient sewage  
66 water treatment facilities or even effluent collection networks. These deficiencies may partially  
67 contribute to an unmanaged artificial recharge of urban aquifers through leakages, that by definition  
68 are difficult to valorize for sustainable uses. In Southern metropolises, this weakness of centralized  
69 networks to face population needs is amplified by overurbanization, here defined as the land  
70 consumption rate (surface change of an urbanized land during a period of time - usually one year -  
71 and expressed as a percentage of the land occupied by the city/urban area at the start of that time),  
72 being higher than the population growth rate. For instance, for Abidjan (Ivory Coast), this rate from  
73 1960-2014 is 1.33, confirming a much faster surface than population growth [16]. Similar trends are  
74 observed in coastal Chinese megacities [17].

75 Over a longer time scale, another way to mitigate water access difficulties is to adopt  
76 opportunistic approaches. In cities of developing countries, an increasing use of private, often  
77 illegally, drilled wells, is observed. For instance, Conicelli et al. [18] reported that about 88% of the  
78 2.5 million tubular wells in Brazil, mostly located in metropolises, are illegal. A direct consequence of  
79 such personal initiatives is a range of conflicts with public authorities, because users are also well  
80 owners and claim the ownership of the territory where the resource is located, justifying the  
81 exploitation of the aquifer with minimum control [18]. Meanwhile, Bertrand et al. [19] showed that  
82 contamination hazards in Recife (Brazil) preferentially occur where population density is greater and  
83 where opportunistic water uses through well drilling are more frequent.

84 In this context, Managed Aquifer Recharge (MAR) strategies are mitigating techniques  
85 helping to control the impacts of contamination and overexploitation, assisting other water resource  
86 planning and management levers [20] [21]. Implementing MAR is highly dependent on site-specific  
87 parameters such as the quality and the availability of the groundwater resource, water to be  
88 recharged, local hydrogeology, operation and implementation costs, as well as the availability and  
89 the comparative feasibility of various MAR alternatives. In densely populated cities, new  
90 opportunities and challenges may be identified for areas suffering from impermeabilization of large  
91 soil surfaces, saline intrusion risks, and high potentiality for recharge by precipitation, e.g. through  
92 Aquifer Storage and Recovery (ASR) wells, Aquifer Storage and Transfer Recovery (ASTR) systems, or  
93 River Bank Filtration (RBF) facilities [22] [23] . Although these approaches are technically affordable,  
94 their success over the long term will mainly depend on how production managers and end-  
95 consumers adopt their sustainable use and governance [20]. Hence, the successful management of  
96 water resources mainly depends on human behavior and education, and not primarily on  
97 environmental processes.

98

99 **The “Critical” need to transform (sometimes illegal) flaws into legal strengths or why implementing**  
100 **MAR in socio-environmental observatories?**

101 Groundwater systems are part of the so-called “Critical Zone” (CZ), which is the  
102 biogeochemical reactive layer of the Earth’s surface exposed to the increasing pressure of  
103 anthropogenic activities [24]. As stated by the philosopher Latour [25], however, this physical  
104 definition may be completed by a more philosophical and challenging perspective: “To study, to live,  
105 to own, to survey or to police a critical zone is not at all the same thing as a piece of land or a  
106 territory”, as the territory could not suddenly disappear under stress, while the critical zone could  
107 malfunction and “be ruined”. Groundwater managers and consumers unfortunately often adopt  
108 denial of reality (and of the risk of disappearance of freshwater) as a cognitive strategy, which can  
109 partly be explained by the apparent abundance of water in some tropical urban areas (vicinity of the  
110 sea and large rivers, intense rainfall, etc.) [12]. Demonstration of socio-institutional denial about  
111 ecological issues is a major result in environmental sociology (e.g., [26]).

112 Although it is counterintuitive at first sight, these denials are concurrent with the previously  
113 mentioned opportunism to access alternative resources, such as illegal wells, because the recovery of  
114 drinking water is a daily challenge especially where the public investments for the installation and  
115 the maintenance of water distribution are insufficient. Asprilla- Echieverra [27] pointed out that this  
116 “heterogenous property scheme of groundwater” exists, especially where alternative strategies for  
117 groundwater access are found: water distributors who request permits for groundwater pumping,  
118 consider the resource as a centrally-managed resource, while “illegal” appropriators perceive the  
119 groundwater as an open access resource, without any coordinated management. This dimension can  
120 be related to the economic theory framing common-pool resources (CPR): the impacts of pumping  
121 and external costs are generally unknown or difficult to establish and benefits in conserving the  
122 resource will only occur in the future. This promotes unsustainable use and the so-called “ myopic”

123 behavior or “business as usual”. However, there is evidences that many individuals benefit from CPR  
124 not by real necessity, but by egoism and selfishness [27] [28] [29].

125 Therefore, people and stakeholders must realize, in a quantitative manner, that management  
126 decisions and resource use impact directly (either positively or negatively) natural processes.  
127 However, in case of repeated freshwater scarcity (contamination, restrictions), one can observe  
128 defiance within the population that loses confidence in public policies and stakeholders [13], and  
129 reciprocally some kind of contempt of the stakeholders for end-users [30] [31]. Furthermore, when  
130 community-driven networks exist, the population is strongly reluctant to adopt public or private  
131 solutions [30]. Thus, the intense fragmentation of networks in southern metropolises complexifies  
132 top-down solutions, partly because territory reflects intense power issues [32], strengthening the  
133 need to transform the local “territory” into a “critical zone” as proposed by Latour.

134 The twofold definition of the CZ introduced above has two consequences. At first, there is a need  
135 to document precisely pollution (anthropogenic contamination, salinization) and flux dynamics at low  
136 and high temporal resolution because these processes are impacted by long-term inertial (*e.g.*,  
137 climate, seawater level) and “catastrophic” processes (*e.g.*, depression due to intense pumping,  
138 major tides, floods) [9]. Combining high and low-frequency hydrogeological monitoring is a key  
139 competence of CZ researchers [33]. To prepare this contribution, we reviewed the literature to  
140 evaluate the temporal and geographical density of such monitoring facilities. Surprisingly, while  
141 short-term hydrogeological case studies are widely documented due to the extensive range of  
142 hydrogeological situations found in urban areas, we identified only a few references for long-term  
143 monitoring in a management perspective [34] [22]. In addition, most of these studies did not  
144 combine high and low-frequency monitoring, include parameters essential for the understanding of  
145 salinization, contamination mechanisms [35] or drivers of water-table variations [22] nor discuss  
146 alternative management policies. Of course, some authors quoted the existence of long-term  
147 databases, mainly from manager monitoring programs. However, these datasets are often

148 fragmented, whereas complete and regularly updated data are scarce. Therefore a very tight  
149 collaboration between researchers and managers is necessary to valorize better existing databases  
150 and to use them in a scientifically validated way [36].

151 Second, accounting for the “geopolitical” dimension of the groundwater resource in the CZ is not  
152 only a matter of hydrogeological monitoring but also a question of “socio-environmental” or “social-  
153 ecological” observation (SEO), an approach that has emerged in the 90’s especially in Northern  
154 countries [37]. SEO’s are research structures focusing on a specific area or over a range of sites  
155 illustrating a given socio-environmental challenge (and therefore including stakeholders) faced by the  
156 society. They aim to concurrently document sociological, anthropological, and ecological (*largo*  
157 *sensu*) dimensions together with long-term monitoring of environmental processes, as it is currently  
158 ongoing throughout, *e.g.*, the International Long-Term Ecosystem Research (ILTER) network [38] or  
159 the upcoming European eLTER research infrastructure (<https://elter-ri.eu/>). Despite ILTER is not an  
160 exhaustive consortium of socio-environmental observatories (SEOs), the only observatories focusing  
161 on urbanized areas and observing groundwater referenced in the related Dynamic Ecological  
162 Information Management System (DEIMS) [39] database are located in Europe (3 sites over 1237  
163 sites), thus far away from Southern metropolises.

164 Therefore, the key question is how to combine the scientific need to characterize socio-  
165 environmental dynamics, the need of public authorities to better control and manage groundwater  
166 resources, and the owner perspective aiming at mitigate the restrictions in water uses? A potential  
167 solution must consider the great extent of private (and often illegal) wells, the territorial  
168 fragmentation due to individual strategic choices and community self-help initiatives, and the  
169 growing scarcity of freshwater resources. In this context, a form of “public/private opportunism” to  
170 implement MAR in SEOs might be a promising way. Implementing MAR using a part of the private  
171 wells would allow to fill the gap between decentralized private/opportunistic and centralized  
172 public/sharing water supply strategies (Fig. 2), and at least partially bring back the “open access



173 resource” to the “managed field”. Similarly, Foster et al. [40], focusing on African urban  
174 development, argue for “decentralized closed-loop water-service systems” to rapidly account for  
175 accelerating water demand and limit dependence on more expensive centralized linear water-service  
176 systems.

177

## 178 **The interest of hybrid top-down and bottom-up co-governance or how implementing MAR** 179 **in SEOs?**

180 Centralized public water supply systems have established boundaries between  
181 stakeholders/managers and end-users, in contrast to decentralized local systems (street, allotment)  
182 [41]. This review recalls that individual or community strategies, including illegal ones, are common  
183 in Southern cities, often making these boundaries irrelevant in the everyday life of many consumers.  
184 Strategic partnerships could replace or improve inefficient centralized top-down organizations [29]  
185 and consistently, co-management structures have in the past essentially been tested in agricultural  
186 areas where large amounts of groundwater are required (e.g., [42] [29] [43] [44]).Dobbin and Smith  
187 [43] stated recently that there is still little feedback on how to implement the acquired experiences  
188 and theoretical knowledge into an organizational strategy. Concurrently, a so-called “Public Private  
189 People Partnership” (PPPP) applied to MAR, was recently experimented in an agricultural region in  
190 Castilla y Leon (Spain) [45] and reveals that, to be operational, the cooperation scheme must allow to  
191 easily access good quality data (at a fine spatio-temporal resolution) [36] and limit the transaction  
192 costs for users and managers [42], especially the monitoring and enforcement costs. These costs  
193 corresponds to what interests SEO’s, and on this basis, we review which are the cognitive, social,  
194 environmental, economic, and governance conditions to favor co-management and illustrate their  
195 implementation through ASR and/or ASTR. These techniques are the likely most affordable (despite  
196 being more expensive in an absolute cost evaluation compared to other techniques such as

197 infiltration basins), see [46]) and easy to implement in (over)urbanized areas to evaluate how these  
198 favorable conditions could be met.

199           From a cognitive perspective, i.e., at the individual scale, co-management implies that a  
200 common objective among end-users is targeted; in the framework of groundwater resources, this  
201 means that common threats are perceived credibly and transparently by users and testify the bad  
202 exploitation of the resource and its consequences [42]. These common threats may be of  
203 environmental (water table decrease, well salinization or contamination) or legal/social nature  
204 (temporal water restrictions, closing of wells) [42] [29]. Here the SEO scientists may provide  
205 scientifically constrained data and subsequent modeling to show the trends over the resource, what  
206 is recognized be highly necessary for MAR [20]. Nowadays, the Internet of Things together with  
207 smart sensors installed at neuralgic points of the water management system (water level, electrical  
208 conductivity, turbidity meters, pluviometry) allow to visualize online the state of the groundwater  
209 resource in a simple web page or smartphone application, as recently proposed in the SMART-  
210 Control project for MAR facilities, which implement ASR and ASTR in NE Brazil. This is expected to  
211 favor the “linking social capital“, i.e., the bi-directional top-down and bottom-up relationships  
212 between end-users, stakeholders, and the scientific community, but also the so-called “citizen  
213 involvement”[36].

214           From a social point of view, this civic participation might be supported by the community-based  
215 social marketing applied to water resources, provided that some populations are more influenced by  
216 social norms than by a real perception of environmental risks . Consistently, Dobbie and Smith [43]  
217 illustrated in a rural area in Honduras that more uniform social norms favor the more efficient  
218 management of water treatment plants. This latter strategy is therefore conditioned to a somewhat  
219 “social homogeneity” favoring trust and the “bonding social capital”, i.e., the sharing and reciprocity  
220 of social values among the users [42], promoting a form of “hydro-solidarity” [47] [48] that may  
221 improve coordinated water management. In contrast, where groundwater users have unequal means

222 and power, and divergent interests, it is hard to reconcile their objectives [42]. In the case of a SEO  
223 for MAR, this aspect can relatively easily be checked previously to the implementation and further  
224 monitored, due to the somehow restricted perimeter of influence of MAR.

225 Cognitive and social related levers mentioned above, to be operational, require also economic  
226 and institutional models that are supportable and acceptable by each part of the co-management  
227 consortium. At first sight, the economic feasibility of MAR remains a complex subject as one may  
228 have difficulties in evaluating economic benefits and risks, particularly the effect of possible system  
229 under-performance [49]. However Gao et al. [50] simulated for the city of Perth (Australia) that  
230 water injection in aquifers in order to implement a “strategic storage” (helping in facing drought or  
231 network shortage) can provide a relatively low-cost insurance for cities with suitable aquifers. The  
232 cost savings depend on the aquifer loss (through lateral flows [51]) but the authors stated that the  
233 solution is still attractive compared to solutions that exclude water banking, e.g., desalinization.  
234 Consistently, Ross [52] stated that evaluating benefits may be performed from the costs of the next  
235 best alternative solution and the value of production using recharged water. Other methods such as  
236 the “willing-to-pay” may be performed and require information’s from the end-users [49]. Therefore,  
237 although Cost-Benefit analysis of MAR systems is site specific, we argue that in densely populated  
238 areas suffering water shortages, MAR is expected to be likely economically viable provided that high-  
239 value uses (and even economically inestimable in case of catastrophic events as a total water  
240 network shortage) such as potable and some industrial water supplies, are performed [49]. Beyond, a  
241 major economic argument to implement MAR in a SEO in densely drilled area is that existing wells  
242 can be transformed into ASR or ASTR injection wells. In some cases, the original well owners would  
243 already cover a part of the capital costs for well constructions (Table 1). It would be however  
244 dampened by lower energy costs related to easier pumping thanks to shallower groundwater level  
245 after MAR implementation [45]. In parallel, integrating MAR in SEO may also positively influence the  
246 cost-benefit analysis equation for the stakeholders in term of information acquisition through  
247 hydrogeological and socio-environmental monitoring by the research community. Recently, based on

248 the proposed approach by Ross and Hasnain [46], the evaluation of levelized costs has been  
249 performed for a range of MAR sites mainly localized in Northern countries [52]. Levelized cost of  
250 MAR is the constant level of revenue necessary each year to recover all the expenses over the life of  
251 the project (assumed to be 30 years by Ross [52]) divided by the annual volume of water supply and  
252 allow a direct comparison with other water access alternatives.

253         These socio-economic boundary conditions must be translated into a governance framework  
254 (Fig. 3). In this perspective, the pressure–state–response (PSR) model has been broadly used in  
255 various SEO and shown to be efficient in producing indicators for socio-ecosystem management [53].  
256 The same institutional actors as the centralized and multi-layered governance (Fig. 1) may be  
257 integrated (white squares). The international and national scale managers (*e.g.*, UN representative’s  
258 group such as IPCC) provide global or regional information about future climatic and demographic  
259 trends, and international strategies remain rather external to the observatory itself. Secondly, the  
260 state/regional water/urbanization/health agencies are expected to supply hydrological, land use and  
261 health screenings for the regional groundwater catchment. Local (metropole scale) authorities  
262 manage/monitor the local water resource and define the duties and right in water injection and  
263 pumping. This approach is largely inspired by feedbacks from regions that have already earlier  
264 experimented with MAR institutionalization. For example, since 1986 the Arizona state (USA) delivers  
265 a range of permits, mainly to public and industrial actors, to perform MAR, provided that the  
266 recipient demonstrates its technical, hydrogeological, and environmental feasibility. This leads to a  
267 permitted storage volume that can be transparently consulted online [54]. In this framework, the  
268 “recovery well permits” impose an equilibrium between the injected and extracted water volumes. In  
269 contrast to the multi-layered and centralized institutional organization, the end-consumers which are  
270 in this scheme considered as critical components and no longer as “unengaged and silent observers”  
271 [53] have representative in the management structure.

272 Finally, Critical Zone and human science researchers must consider the interfaces between  
273 regional, local, and the SEO scales as well as the interactions between stakeholders and consumers  
274 (linking social capital), between each end user (bonding social capital) and potentially with the users  
275 outside the SEO perimeter (bridging social capital). This role is quite often endorsed by non-  
276 governmental organizations in developing countries, especially in rural areas but we argue that a  
277 greater scientific implication would also benefit to the research communities (consolidated data  
278 acquisition), as it was suggested by Foster [55]. Here their missions are to ensure data operation  
279 (collection, concatenation, organization) in a recoverable way with and for each actor, *e.g.*, usable for  
280 building adapted indicators to evaluate the hydrogeological, environmental, and sociological impacts  
281 on the MAR implementation over the long-term. Consistently, for each arrow in Fig. 3, representing  
282 socio-environmental and water flux drivers, or resource responses to MAR operations, indicators  
283 should be delineated. Zheng et al. [56] recently proposed specific indicators for MAR regarding  
284 groundwater quantity (long-term water table change, annual ratio of recovered vs infiltrated water),  
285 quality (temporal exceedance rate of recovered/ambient water or source water), ecology (*e.g.*,  
286 changes in ecological flow in adjacent ecosystems), energetic stress (energy requirement for each  
287 recovered cubic meter) and social sustainability (*e.g.*, related to governance transparency).

288 This institutional organization should favor research –action programs and is expected to  
289 lead to a renewed approach for interdisciplinary programs. As mentioned by Flyvbjerg [57], social  
290 science matters when it defends a perspective that Aristoteles called “*phronesis*”, meaning that the  
291 presence of social scientists is not only tied to the measure of social acceptability, but mainly to the  
292 democratic and pedagogical dimensions of socio-technical projects, in order to increase the  
293 reflexivity of the partners.

294

295 **Conclusion and perspectives**

296           This paper aimed to review two dimensions appearing as promising to face long-term  
297 groundwater-related challenges in southern densely populated areas by implementing MAR  
298 (Managed Aquifer Recharge). The first one is the role of SEOs (Socio-Environmental Observatories).  
299 To be operational over the long-term, SEOs must be as interactive as possible by integrating the  
300 three above-mentioned communities (managers/stakeholders, end-users, scientists), mainly because  
301 MAR strategies require public acceptance and trust, which has decreased a lot in cities with repeated  
302 domestic water shortages [12]), as well as dialog triggered by experts. The implementation of SEO is  
303 part of the perspective of institutional recognition of a problematic situation and its originality comes  
304 from the effective (and not just formal) inclusion of users in their management. In this sense, it is a  
305 question of recognizing the errors of a centralized management of water, and of considering that  
306 various mechanisms of participation and/or deliberation prove to be essential if it is a question of  
307 modifying the social practices. Informal alternative water access strategies in Southern metropolises,  
308 often illegal, demonstrate that non-coordinated decentralization already exists in order to mitigate  
309 centralized system failures. Decentralized but co-governed structures constitute therefore a third  
310 way to better manage urban water cycles. Such structures are easier to implement than centralized  
311 and expensive management systems and should favor water user's security by providing services like  
312 resource monitoring and analysis [58].

313           This co-management scheme for MAR in SEO, however, could still evolve by integrating a  
314 new institutional actor, the water resource itself (Fig.3). Legal recognition of ecological elements such  
315 as rivers or mountains already exists [59]. Groundwater - whose invisibility is one of its significant  
316 characteristics - should similarly achieve legal recognition to benefit from institutional innovations  
317 such as hybrid forums or spokespersons that would have the responsibility to defend "their client"  
318 with institutional autonomy. As defended by the Actor-Network Theory, it would also highlight the  
319 agency of so-called natural elements.

320

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507

#### 508 **FIGURE CAPTIONS**

509 **Figure 1: Conceptual scheme of the imbricated multilayer water system in Recife (Brazil). The**  
510 **water resource is located in 3 geological layers; is managed by a multilayer governance system and**  
511 **may be consumed/used through various decentralized strategies, related to the contrasted socio-**  
512 **environmental integrations of the population. Under global climate forcing and local demographic**  
513 **pressures, this may lead to conflicts i.e. risks from quantitative, qualitative and social (e.g.,**  
514 **sanitary) points of views, which face some institutional and individual denials.**

515

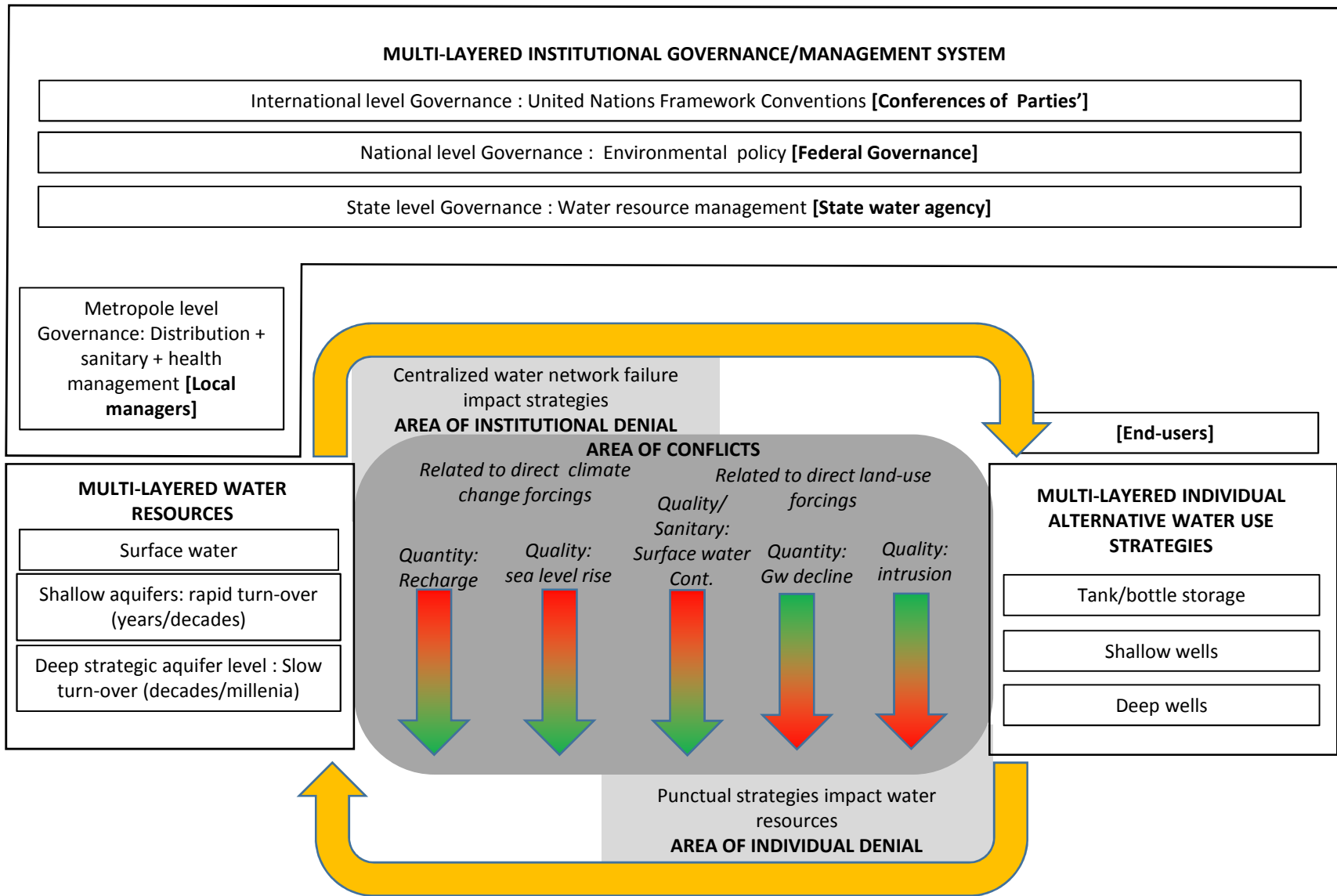
516 **Figure 2. Range of individual strategies in Recife (Brazil) to face water resource shortage in poorly**  
517 **managed and/or under catastrophic conditions (i.e., droughts, floods, general domestic water**  
518 **network contamination). Pictures from Cary et al. (2018) or from G. Bertrand.**

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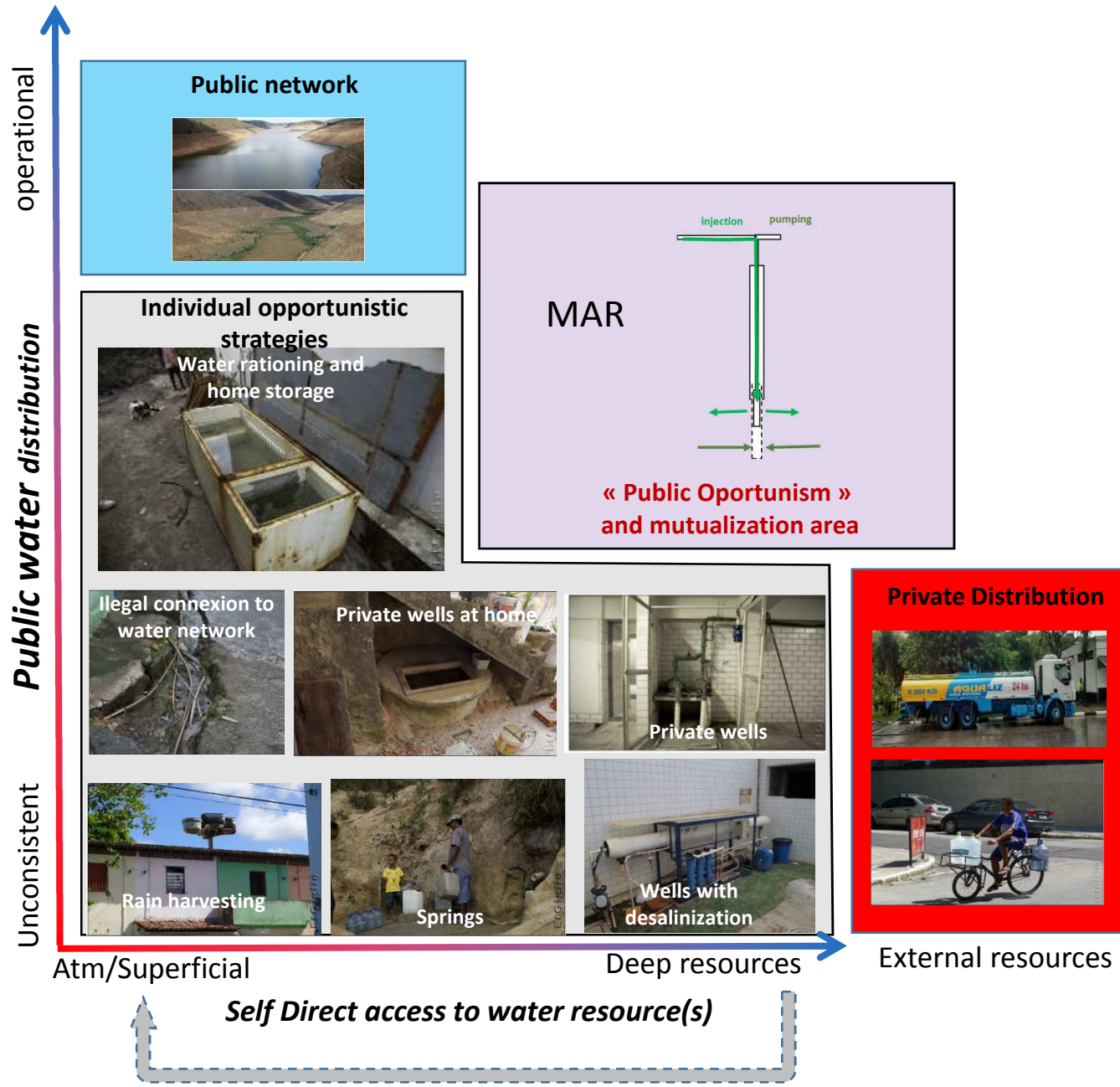
520 **Figure 3. General structural pattern of a socio-environmental observatory focusing over MAR**  
521 **implementation in urban environment. The same actors as in Fig. 1 are found (white squares).**  
522 **Researchers community works at the interfaces between regional and local scales as well as at the**  
523 **interface between large scale or local managers and end-users. For each arrow representing socio-**  
524 **environmental or water flux drivers or resource responses to MAR operations, indicators should be**  
525 **delineated making the hydrological and socio-environmental processes accessible to users and**  
526 **managers. The water resource itself might be integrated as a management consortium member, if**  
527 **its recognition as a juridical person is processed.**

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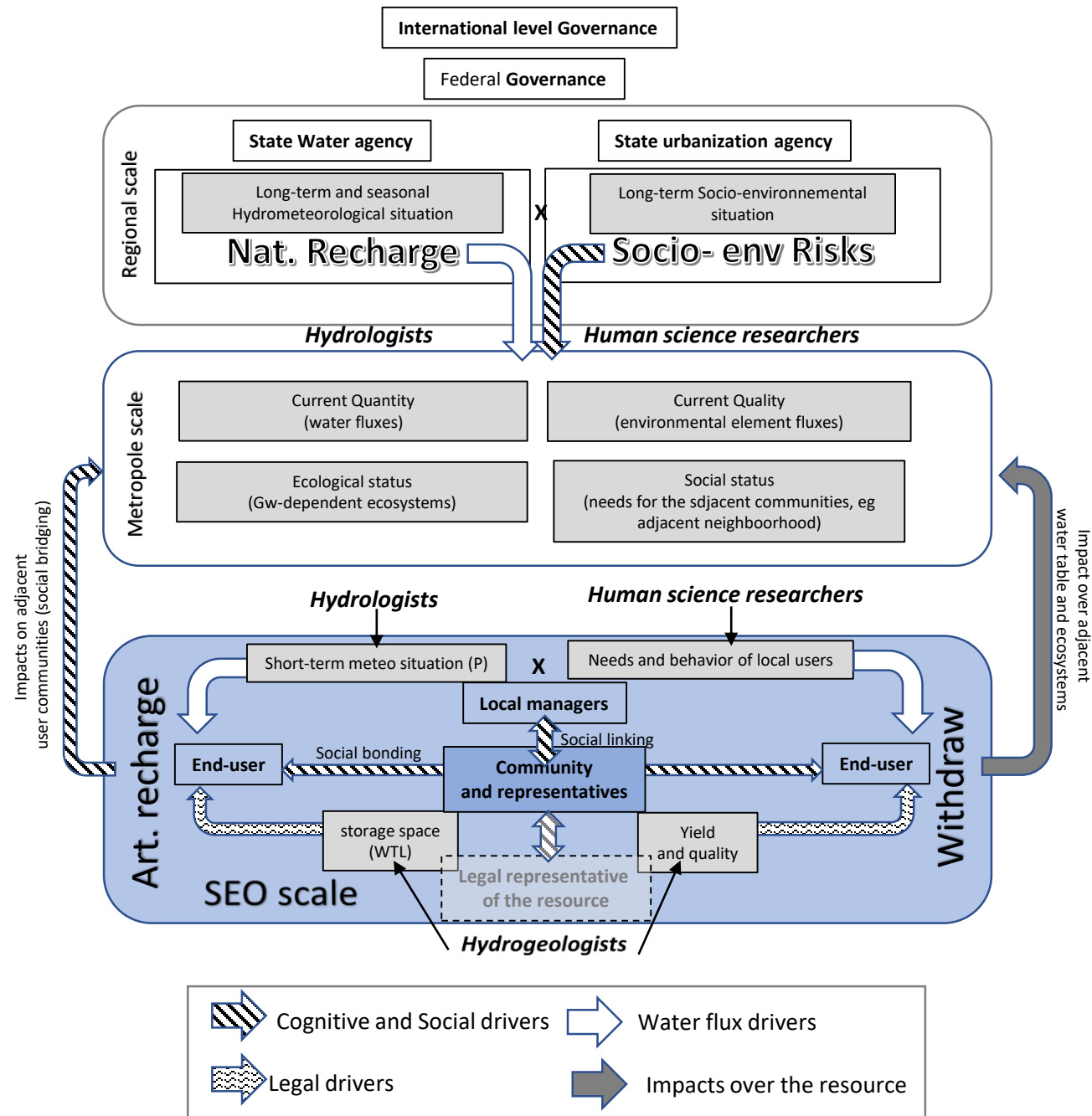
529 **Table 1: Cost distributions of MAR implementation in a SEO.**



*Climate change impacts x Lack of investments*



*Climate change impacts x increase of individual strategies leading to salinization*



|  | Costs for the owner  | Costs for stakeholders   | Costs for SEO structure  | Surrounding users | Remarks   |
|--|--|--|--|-------------------|---|
| Capital and financial costs (considered as sunk costs) | <ul style="list-style-type: none"> <li>-Feasibility study (hydrogeological investigation)</li> <li>Drilling and well installation</li> <li>Pump acquisition/installation</li> <li>- Building used for Rain harvesting</li> </ul>   | <ul style="list-style-type: none"> <li>- Feasibility study for Rain harvesting,</li> <li>- Roof pipes and filtering unity before injection well</li> </ul>                                 | <ul style="list-style-type: none"> <li>- Sensors and telecommunication</li> <li>- Visualization platform (software + hardware)</li> </ul>  | N.a.              | <p>In case of handmade wells, additional costs for well evaluation prior MAR scheme implementation is required (potentially partially covered by stakeholders)</p> <p>Debt service payment are not indicated but should be included in case loans were taken.</p>   |
| Opportunity costs (considered as sunk costs)           | In the case of existing private well is used for ASR or ASTR, that should be a common model in densely urbanized area, the opportunity costs related to land selling or for building are neglected considering that ASR does not consume a large surface, that can still be used for other purposes. |  |  | N.a.              | N.a.  |
| Operation and Maintenance costs                        | <ul style="list-style-type: none"> <li>- Electricity for Pumping</li> <li>- Injection Well maintenance</li> <li>- Operational labor costs (injection survey)</li> </ul>  | <ul style="list-style-type: none"> <li>-Filter and pipes maintenance services</li> <li>- Administrative labor costs</li> <li>- Communication and valorization actions to public</li> </ul> | <ul style="list-style-type: none"> <li>- Consulting service labor costs (water quality and quantity monitoring, analyzing and reporting, sociological analyses</li> <li>-Sensor maintenance</li> <li>-Communication and valorization actions</li> <li>- Formation</li> </ul> | N.a.              | <p>Injection well maintenance costs could be divided between owners and managers as an incentive for owners</p> <p>Fixed costs (electricity, offices) are not indicated as they correspond to the functioning of the institutions but should be formally included in the economic plan</p>  |
| Social (non financial) costs/capital                   | <ul style="list-style-type: none"> <li>-Participation to the co-governance or election of a representative</li> <li>- Social mobilization through participative communication</li> </ul>   |  |  |                   | Participation of surroundings users (in the same neighborhoods or under influence of recharge strategy) could be proposed as they benefit from the MAR. This can strengthen the bridging dimension of the social capital since bounding social capital is assumed to exist prior the project and linking social capital dimension is developed through the co-management functioning. |