



**HAL**  
open science

# Valuing a diversity of ecosystem services: The way forward to protect strategic groundwater resources for the future?

Cécile Hérivaux, Marine Grémont

## ► To cite this version:

Cécile Hérivaux, Marine Grémont. Valuing a diversity of ecosystem services: The way forward to protect strategic groundwater resources for the future?. *Ecosystem Services*, 2019, 35, pp.184-193. 10.1016/j.ecoser.2018.12.011 . hal-01975179

**HAL Id: hal-01975179**

**<https://brgm.hal.science/hal-01975179v1>**

Submitted on 11 Jan 2019

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

1 **Valuing a diversity of ecosystem services: the way forward to protect strategic groundwater resources for**  
2 **the future?**

3 Cécile Hérivaux <sup>a,\*</sup>, Marine Grémont <sup>b</sup>

4 <sup>a</sup> BRGM, Univ Montpellier, 1039 rue de Pinville, 34000 Montpellier, France, +33.4.67.15.79.71, [c.herivaux@brgm.fr](mailto:c.herivaux@brgm.fr)

5 <sup>b</sup> BRGM, Univ Montpellier, 1039 rue de Pinville, 34000 Montpellier, France, [marine.gremont@gmail.com](mailto:marine.gremont@gmail.com)

6 \* Corresponding author

7  
8 **Abstract**

9 This paper demonstrates the usefulness of valuing a diversity of ecosystem services for groundwater protection.  
10 It argues that improving the understanding of local stakeholders regarding the benefits that strategic groundwater  
11 preservation for future generations can bring to their territories is a relevant mean to enhance their support  
12 towards groundwater conservation. We develop and test a systemic approach based on local data collection, cost-  
13 based monetary valuation methods and stakeholder involvement. The paper reports on empirical work conducted  
14 in a strategic groundwater area located in Southern France, that could be of interest in the future to supply the  
15 growing population of coastal urban areas. We characterize, quantify and value in monetary terms nine  
16 ecosystem services. We then analyze the perception of the proposed approach, ecosystem services and associated  
17 monetary values by organising a workshop involving 25 local stakeholders. Overall, participants validate the  
18 operational feasibility and the relevance of the approach for raising awareness and bridging the gap between  
19 environmental issues, which can be effective triggers to the implementation of protection action. Yet, monetary  
20 valuation provides only partial insights into the overall value of the benefits of protecting the strategic  
21 groundwater area, and would improve from being articulated with socio-cultural valuation methods.

22 **Keywords:** groundwater protection, drinking water safeguard zones, ecosystem services, monetary valuation.

## 1           **1. Introduction**

2   Providing almost half of drinking water worldwide, groundwater resources are of primary importance for human  
3   consumption (Smith et al. 2016). The availability of good-quality groundwater is a major concern for the  
4   estimated 2.5 billion people that rely solely on groundwater to satisfy their daily water needs (WWAP 2015).  
5   Yet, over the long term, the ability of groundwater resources to fulfil these needs is likely to be compromised by  
6   projected global changes. Demographic growth will increase global demand for freshwater. Meanwhile,  
7   continued urbanization, unsustainable agricultural practices and climate changes are expected to reduce  
8   groundwater recharge and jeopardize water quality (Jiménez Cisneros et al. 2014; MEDDE 2013), increasing  
9   thereby the vulnerability of entire water supply systems.

10   Since the 1960s, awareness has progressively risen among land managers and policy makers regarding the  
11   vulnerability of communities to groundwater resource pollution and depletion, stressing the need to secure  
12   current and future water supply. In many countries, this led to establish drinking water protection areas (DWPA)  
13   designed to improve the quality of groundwater resources currently used for drinking water supply. Following  
14   the requirements of the European Water Framework Directive (article 7.1), French water agencies have recently  
15   included the establishment of drinking water safeguard zones (DWSZ) in their river basin management plans.  
16   Compared to standard DWPA, the newly established DWSZ cover strategic good-quality groundwater resources  
17   with a high productive potential that are located close to future high-consumption areas. These resources are  
18   used or not for human consumption, but they are of great interest for future drinking water supply. For local  
19   water managers, the objective is not to restore good-quality but to guarantee that in the future, land-uses and  
20   management practices will remain compatible with the maintenance of a good-quality groundwater resource.

21   Currently in France, there is no clear view on the policy instruments that will support the protection of the  
22   dozens of recently delineated DWSZ. A large range of policy instruments has already been implemented to  
23   protect groundwater resources used for drinking water production: e.g., legal instruments for public land control  
24   and land use regulation (Blanchard et al. 2015; Pivot and Aznar 2000), water related agri-environmental  
25   measures, or voluntary agreements (Barraqué and Viavattene 2009). However, most of them are not legally  
26   enforceable in case of unused strategic groundwater whose potential exploitation could benefit future  
27   generations. Due to the non-binding nature of these zones, the effective protection of DWSZ may face several  
28   challenges in practice (Hérivaux and Grémont, 2015). First, benefits of groundwater protection policies for  
29   drinking water are only likely to materialize in the long term, and their beneficiaries are hardly aware of their

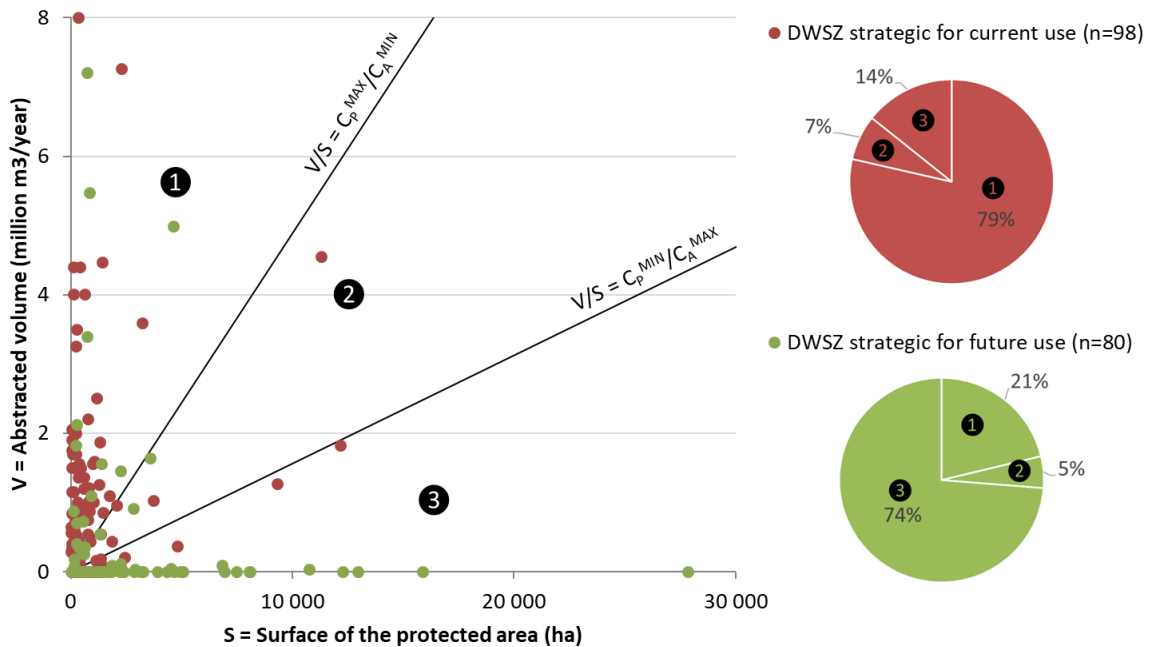
1 existence, while protection costs are immediate, tangible, and affect well-organized vested interest groups (e.g.  
2 businesses, farmers). Thus, land managers struggle to advocate for protection policies when they are faced with  
3 competing development projects likely to bring, over the short term, new markets and employment to local  
4 economies. Second, because they are legally responsible for continuity of water supply, water services tend to  
5 prefer engineered solutions (e.g. treatment plants, network interconnections) whose effects are easily monitored,  
6 to groundwater protection policies whose effectiveness and time delay may be highly uncertain. Finally, the lack  
7 of coercive groundwater protection measures for unused strategic groundwater and the relative small amounts of  
8 available public financial resources dedicated to their preservation, which do not outweigh the costs of most  
9 required land-use changes, provide little incentive for stakeholders to implement ambitious policies. We argue  
10 that one powerful lever to overcome these barriers is to enhance the support of local stakeholders, by improving  
11 their understanding of the economic benefits that groundwater preservation can bring to their territories.

12 This paper first introduces the shortcomings of conventional economic approaches for assessing the overall long  
13 term economic benefits of preserving strategic groundwater resources. It proposes a systemic approach  
14 accounting for the diversity of ecosystem services provided by DWSZ, based on local data collection, cost-based  
15 monetary valuation and stakeholders involvement. It then investigates the operational feasibility of the approach  
16 through a case study located in Southern France and demonstrates its relevance for raising awareness and  
17 knowledge of the economic benefits provided by DWSZ protection.

## 18 **2. Shortcomings of conventional economic valuation of the benefits of DWSZ protection**

19 Two types of monetary valuation methods are commonly used to assess the economic benefits of groundwater  
20 protection: the avoidance-cost method and the contingent valuation method. However, both face limitations for  
21 assessing the long-term benefits of DWSZ protection. The avoidance cost method (e.g., see Abdalla 1994;  
22 Rinaudo et al. 2005) consists of assessing the costs of *averting and defensive* actions undertaken by economic  
23 agents to cope with groundwater degradation (e.g., closing and relocating wells, building water treatment plants,  
24 purchasing bottled water), considering that these costs would be *avoided* if the resource was not degraded.  
25 Comparing these avoided costs to the costs of protection policies can typically help strengthen the rationale for  
26 groundwater protection on DWSZ characterized by a low ratio of protection costs over avoided costs. Since  
27 protection costs depend upon the surface of the protected area and avoided costs depend upon the abstracted  
28 volume of water, the cost of watershed protection can be more easily justified in watersheds where  $S \times C_p < V \times$   
29  $C_A$ , that is when  $V/S > C_p/C_A$ , where  $S$  the surface of the protected area (ha),  $C_p$ , the protection costs (€/ha/year),

1 V the abstracted volume ( $\text{m}^3/\text{year}$ ), and  $C_A$ , the avoided costs ( $\text{€}/\text{m}^3$ ). To illustrate this point, Figure 1 depicts the  
 2 abstracted volumes and surfaces of 178 DWSZ recently delineated in France. We distinguish DWSZ that are  
 3 already considered as strategic for current use, from DWSZ deemed strategic for future use. From there, let us  
 4 draw two lines based on the following orders of magnitude taken from the literature: avoided treatment costs  
 5 ranging between 0.46 and 0.80  $\text{€}$  per abstracted cubic meter<sup>1</sup> and protection costs ranging between 125 and 250  
 6  $\text{€}/\text{ha}/\text{year}$ <sup>2</sup>. Avoided costs may be sufficient to justify by themselves the protection costs of 79% of the DWSZ,  
 7 which are already used for drinking water. **On the other hand**, avoidance costs can hardly be used to justify the  
 8 protection of 74% of the DWSZ delineated for future use, and characterized by low V/S ratios, as future drinking  
 9 water abstraction are typically unknown.



10

11 Figure 1. Abstracted volume and surface of 178 DWSZ recently delineated in France. Estimates of the  
 12 proportion of DWSZ for which protection measures can be economically justified by the avoided treatment costs  
 13 (1 and 2) or not (3). Considered avoidance costs ( $C_A$ ) vary between 0.46 and 0.80  $\text{€}/\text{m}^3$  produced;  
 14 protection costs ( $C_P$ ) vary between 125 and 225  $\text{€}/\text{ha}/\text{year}$ .

<sup>1</sup> In France, Bommelaer and Devaux (2011) estimates that water treatment costs range from 0.40 to 0.60  $\text{€}/\text{m}^3$  for the treatment of nitrates and from 0.06 to 0.20  $\text{€}/\text{m}^3$  for the treatment of pesticides.

<sup>2</sup> We use here the average drinking water watershed protection costs of the cities of New York and Munich, often used as examples to illustrate that groundwater protection may be cheaper in the long run than curative actions. In New York, the Catskill watershed (518 000 ha) protection program costed the community 1.15 billion  $\text{€}$  from 1997 to 2007, i.e., 225  $\text{€}/\text{ha}/\text{year}$  (Barraqué and Viavattene 2009; Chichilnisky and Heal 1998; Grolleau and McCann 2012). Similarly, the German city of Munich implemented a preventive program costing 750 000  $\text{€}/\text{year}$  to protect a 6000 ha watershed for drinking water, i.e., 125  $\text{€}/\text{ha}/\text{year}$ .

1 Stated preferences methods, such as the contingent valuation method (Poe et al. 2000; Hérivaux and Rinaudo  
2 2016), are alternative conventional approaches used for assessing the benefits of groundwater protection. The  
3 contingent valuation method relies on the implementation of surveys to elicit people's willingness to pay for  
4 hypothetical environment improvement scenarios. This approach enables to highlight people's preferences  
5 towards groundwater protection, and economic values, which are not directly related to the use of groundwater.  
6 An abundant literature describes the potential bias associated with the use of the contingent valuation method for  
7 valuing environmental goods (Venkatachalam 2004). Hérivaux and Rinaudo (2016) suggest that there are  
8 additional problems related to the specific characteristics of groundwater. The first major concern is that  
9 respondents may have a very limited knowledge of the environmental asset they are asked to value, especially  
10 when they do not use groundwater directly as it is the case for [DWSZ strategic for future use](#). The second  
11 [limitation](#) is related to embedding effects: people may be unable to assess the benefits derived from the  
12 protection of a specific delineated groundwater resource, as (1) groundwater is generally perceived as a  
13 uniformly distributed resource and (2) groundwater management actions are expected to bring a wide range of  
14 environmental benefits. This casts doubt on the meaning of the individual preferences elicited by the survey.  
15 Finally, the avoidance cost and the contingent valuation methods both refer to benefits directly related to  
16 groundwater, without considering [co-benefits](#) generated by protection policies.

17 Yet, as DWSZ protection generally consists in maintaining land-uses and activities compatible with good-quality  
18 water, the benefits of groundwater protection may go well beyond water security and cover a wide range of co-  
19 benefits including protection against erosion, carbon storage, wood production, agricultural production, hunting or  
20 fishing (Abell et al. 2017). Current practices of groundwater policy assessments fall short of adequately  
21 accounting for these multiple benefits (Bouwma et al. 2018). Against this backdrop, several public policies have  
22 highlighted the need to increase sectorial policy integration, including the European Water Blueprint or the  
23 global Aichi targets set by the Convention on Biological Diversity (European Commission 2012; CBD 2010).  
24 This reinforces the interest of assessing the multiple benefits of groundwater management (Abell et al. 2017; Nel  
25 et al. 2017). The ecosystem services valuation framework offers an interesting analytical framework to assess the  
26 wide range of benefits provided by groundwater protection. An abundant literature has emerged on ecosystem  
27 services characterization and valuation since the Millennium Ecosystem Assessment (Costanza et al. 2017; MEA  
28 2005). While it is common practice to characterize the ecosystem services associated to land-use change scenarios,  
29 conservation programs or protected areas (Bateman et al. 2013; Castro et al. 2015; Johnson et al. 2016),  
30 economic assessments focusing on ecosystem services provided by groundwater protection remain scarce

1 (Aguilar et al. 2018) and still mostly focus on water-related services (Brauman et al. 2007; de Groot et al. 2012;  
2 Keeler et al. 2012; Nel et al. 2017; Nelson et al. 2015; Vlachopoulou et al. 2014; Wang et al. 2017). Abell et al.  
3 (2017) address this gap and explore the co-benefits resulting from source water protection investment (including  
4 climate change mitigation and adaptation, biodiversity, and human health and well-being). The recent work of  
5 Aguilar et al. (2018) investigates with a discrete choice experiment how population perceives and values  
6 different ecosystem services arising from forested watershed ecosystems in the US in general, without referring  
7 to any specific watershed. Liqueste et al. (2016) highlight the diversity of benefits provided by nature-based  
8 solutions for water pollution control through a multi-criteria analysis. The present paper contributes to this  
9 emerging trend. It proposes a pragmatic valuation framework enabling to account for the diversity of benefits  
10 provided by protecting strategic groundwater resources for the future. We apply this valuation framework to a  
11 DWSZ located in southern France.

### 12 **3. Material and method**

#### 13 **3.1. Case study presentation**

14 The DWSZ of the *Contreforts Nord de la Sainte-Baume* is located 40 km from the Mediterranean coast and  
15 covers over 7,400 ha dominated by woodlands and semi-natural areas. The karstic aquifer hosts important good-  
16 quality groundwater volumes that could supply approximately 4 Mm<sup>3</sup> per year, of which only 1 Mm<sup>3</sup> is currently  
17 used for drinking water. This underexploited water resource has been identified by the local French Water  
18 Agency as a strategic resource for urban coastal areas [where](#) water demand is expected to rise significantly in the  
19 coming decades due to both tourism and demographic growth. In a context of increasing tensions over water  
20 resources and strong urban development, failing to preserve the watershed would result in land-use shifts likely  
21 to affect water quality (e.g. urban sprawl, quarry exploitation). Therefore, preserving current land cover on the  
22 DWSZ is a major concern for local authorities.

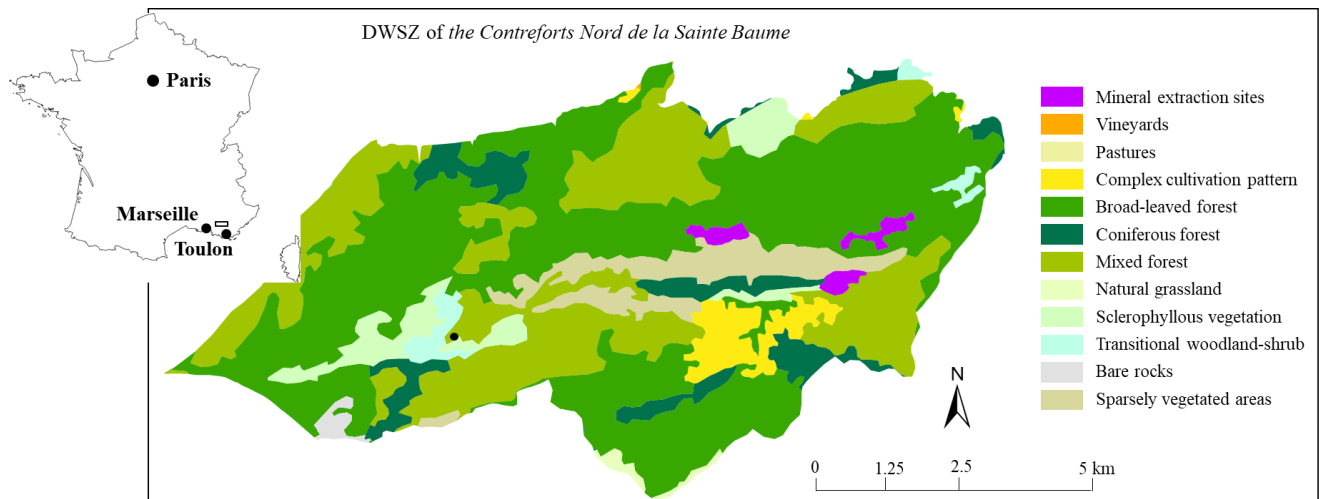


Figure 1. Geographical location and land-cover on the DWSZ (Corine Land Cover)

### 3.2. Overview of the methodological framework

The methodological framework consists in assessing the ecosystem services provided by the DWSZ in order to highlight the multiple benefits stemming from maintaining the area in its current state. In line with the Common International Classification of Ecosystem Services (CICES), we classified ecosystem services into three categories: (i) *provisioning services* that encompass all nutritional, material and energetic outputs from ecosystems from which goods and products are derived (i.e. agricultural and wood production), (ii) *regulating services* that cover all the ways in which ecosystems can mediate or moderate the ambient environment in which people live or upon which they depend (i.e. carbon sequestration and storage, water cycle regulation and flood protection), and (iii) *cultural services* that include all the non-material characteristics of ecosystems that affect the physical, mental or intellectual well-being of people (i.e. hunting, fishing, hiking and speleology) (Haines-Young and Potschin 2018). This classification attempts to describe ecosystem outputs as they directly affect human well-being. As a result, it sets aside supporting services such as biodiversity that are considered as intermediate services that people do not directly use or consume but that contribute to ecological processes and structures without which the provision of other ecosystem services would not be possible (Fisher et al. 2009; Wallace 2007).

Our approach follows three main steps: (1) identification of the set of ecosystem services provided by the DWSZ, (2) characterization and monetary valuation of these ecosystem services, and (3) organization of a workshop gathering local stakeholders in order to present and debate the results of the assessment.



### 3.3. Identification of ecosystem services

Based on the available literature (e.g. urban planning management plans, water utility technical reports) and GIS data (e.g. Corine Land Cover, National Institute of Geographic and Forest Information, agricultural census), a set of ecosystem services likely to be provided by the DWSZ has been identified. Landowners, land users, managers and beneficiaries of these services have been characterized. This first step was completed when necessary with telephone interviews with local stakeholders. It enabled pre-identifying 13 ecosystem services typically provided by the land cover types currently found on the DWSZ as well as the stakeholders involved in their provision.

A series of face-to-face interviews was then carried out with these stakeholders in order to (i) validate the set of ecosystem services provided by the DWSZ and (ii) collect the bio-physical and economic data necessary for the assessment. Interviewed stakeholders included local policy-makers, land managers, state representatives, environmental associations and water utilities. Out of the 13 pre-identified ecosystem services, nine were selected following the interviews. The remaining services were excluded from the assessment due to missing data.

### 3.4. Characterization and valuation of ecosystem services

The information gathered was used to quantify ecosystem services using both bio-physical and socio-economic indicators (e.g. tons of carbon captured, volume of abstracted water). Indicators were then translated into monetary units using mostly price and cost-based monetary valuation techniques (e.g. market prices, replacement costs, avoidance costs). When uncertainties were high, several assessment methods were used to produce a range of benefits. This resulted in estimating an order of magnitude of the minimum economic value of the ecosystem services provided by the DWSZ that reflects the overall benefits of preserving the DWSZ.

The following paragraphs describe the methodology used to assess each individual ecosystem service. Unless otherwise specified, all economic values are expressed in €<sub>2013</sub> and all data refer to the reference year 2010.

#### *Wood production*

Woodlands cover 83% of the area, comprising 4 075 ha of broadleaf trees and 2 028 ha of coniferous trees. Because of low-productivity forests and unorganized supply chains, silviculture brings little revenues to local economies. Accounting for forest proprietorship and related management practices, we estimated that only 67% of woodlands are exploited for wood production on the DWSZ (OFME 2003), [according to a selective harvesting that is based on annual growth rates of trees and maintains forest canopy structure](#). The economic

1 value of wood production was estimated using the market price method that consisted of valuing wood  
2 production according to the market price of standing wood, taking into account that market prices vary according  
3 to the final use (fuel, construction, furniture), and that the final use, in turn, depend upon tree species. According  
4 to local stakeholders, in the region, broadleaf wood is mainly dedicated to firewood for a stumpage price for tree  
5 stands (without exploitation costs) of 10-35€/m<sup>3</sup>. As for coniferous wood, it is delivered to the paper industry for  
6 a price of 10-15€/m<sup>3</sup>. Other outlets for conifers include wood energy and pallet production, for stumpage prices  
7 of respectively 12€/m<sup>3</sup> and 100-130€/m<sup>3</sup>. Due to higher market prices, revenues from broadleaf species are  
8 therefore higher than revenues from conifers. However, annual growth rates of trees are lower for broadleaf  
9 species (1.3-1.5 m<sup>3</sup>/ha/year) than for conifer species (3m<sup>3</sup>/ha/year) (National Forest Office).

#### 10 *Agricultural production*

11 Agricultural lands account for 3% of the area. Production activities are essentially dedicated to mixed crop-  
12 livestock farming, with 25 ha devoted to fruits and vegetables, 362 ha of grassland used for extensive goat and  
13 cattle grazing (99 livestock units), and 93 beehives producing on average 3 tons of honey per year. The  
14 economic value of agricultural production was estimated using the market-based method. Revenues from  
15 beekeeping production were estimated using the average gross operating profit per hives in France (103 €/hive),  
16 taking into account the relative yield differential between the French average (24 kg/hive) and local production  
17 (32 kg/hive) (Union of French Apiculture). Livestock production was estimated using the mean gross operating  
18 profit per livestock unit (LU) in the region for goat farming (Agreste) and cattle farming (Institut de l'Élevage  
19 2012). As for the economic value of land cultivation, it was assessed using mean gross operating profits in  
20 Provence-Alpes-Cote-d'Azur, per hectare, per year, and per type of culture (719 €/ha/yr for fruits, 7 985 €/ha/yr  
21 for vegetables and 9 938 €/ha/yr for horticulture) (French agricultural census).

#### 22 *Carbon sequestration and storage*

23 Forests and grasslands contribute significantly to climate regulation (IPCC 2014). On the one hand, they absorb  
24 carbon-containing atmospheric compounds during photosynthesis. The absorbed carbon is stored within soil (in  
25 organic form) and biomass (both above-ground such as in leaves or branches, and below-ground such as in  
26 roots). On the other hand, they release carbon dioxide through respiration, combustion and decomposition. The  
27 difference between the amounts of carbon absorbed – which depend upon vegetation growth – and released –  
28 which depend upon harvests and tree mortality – is the *annual carbon sequestration*, expressed in t-eqCO<sub>2</sub>/year.  
29 On the long run, the total amount of carbon sequestered over the ecosystem lifetime is the *carbon storage*,

1 expressed in t-eqCO<sub>2</sub>. On the DWSZ, most of the carbon is sequestered and stored in soils and biomass by  
2 forests that account for 83 % of the area.

3 The annual carbon sequestration of forests was estimated using two indicators of the net annual growth rate of  
4 trees provided by the National Forest Office (local average) and the National Institute of Geographic and Forest  
5 Information (regional average). Net growth of trees was then combined with carbon sequestration coefficients  
6 per tree species in France (Loustau 2004). For grasslands, a similar approach was adopted based on national  
7 carbon sequestration coefficients (Puydarrieux and Devaux 2013).

8 The amount of carbon that is stored over the long run varies according to the relative share of carbon that is  
9 stored above and below ground. For forests, the volume of standing timber was estimated based on a regional  
10 average (Institut Forestier National 2012). Two hypotheses were then formulated in line with recent literature.  
11 First, we considered that 2/3 of the carbon stored was stored below ground (in biomass and soils) against only  
12 1/3 stored above ground (Dupouey et al. 2002). Second, we considered that respectively 3/4 and 1/4 of below  
13 and above ground carbon were stored over the long term (Chevassus-au-Louis 2009). For grasslands, carbon  
14 stored in above-ground biomass was considered negligible (Puydarrieux and Devaux 2013). Long-term carbon  
15 storage by grasslands was therefore estimated using coefficients representing the average amount of carbon  
16 stored in soils by south eastern grasslands of France over the long-term (Arrouays et al. 2002).

17 Finally, two valuation methods were used to assess the economic value of carbon sequestration and long-term  
18 carbon storage. The market price method valued each ton of sequestered and stored carbon at the average spot  
19 prices of CO<sub>2</sub> Emission Allowances on the EU Emission Trading System (i.e. 13€/teqCO<sub>2</sub> in 2010). As for the  
20 social cost of carbon method, it valued carbon sequestration and storage at the marginal global damage costs of  
21 carbon emissions, that is the net present value of climate change long-term impacts of one additional ton of  
22 carbon emitted today (Watkiss and Hope 2011). It was assessed using the shadow value of carbon estimated in  
23 France by the Quinet commission to 32€/teqCO<sub>2</sub> in 2010, increasing at a 5.8% annual rate so as to reach 100  
24 €/teqCO<sub>2</sub> in 2030 (Quinet 2008). For long-term carbon storage, a discount rate of 2.5% was used over a 30 year  
25 time period (Quinet 2013).

## 26 *Flood protection*

27 The main flood-related risk on the DWSZ pertains to overflows of the Caramy River. Located at the head of the  
28 river, the DWSZ contributes to flood protection since it is mostly covered by non-artificialized areas (croplands,

1 grasslands, forests) that store large volumes of water underground, reducing thereby runoffs and associated  
2 flooding. Two methods are commonly used to assess the economic benefits of flood protection. The avoidance  
3 cost method (Ninan and Inoue 2013) estimates the damage costs of past events but requires historical data that  
4 was not available in our case study. An alternative method is the replacement cost method that consists of  
5 estimating the volume of water stored by current land cover in order to assess the mean annual cost of an  
6 alternative water storage facility. According to local hydrogeologists, the available water storage capacity in the  
7 limestone soils of the DWSZ ranges from 50 to 150 m<sup>3</sup>/ha. The alternative water storage facility is *assumed* to be  
8 a dam that would be constructed on the Caramy River and whose construction and operation costs were  
9 estimated using the mean costs of five different dams built in France during the past 40 years (Bouscasse et al.  
10 2012). A discount rate of 2.5% was used over a 100 years lifetime.

### 11 *Water cycle regulation*

12 The approach adopted to assess the water cycle regulation service consisted of assessing the benefits associated  
13 with maintaining in its current state a land cover capable of recharging the aquifer (quantity) as well as filtering  
14 and purifying the water during its transfer to the aquifer (quality). The beneficiaries of this service are residential  
15 users whose drinking water is currently extracted from the aquifer. Benefits were estimated by comparing the  
16 current situation with a situation that would require resorting either to another resource for drinking water  
17 supply, or to a water treatment facility. Two valuation methods were used: the avoided costs of water treatment  
18 and the avoided costs of a network interconnection with an alternative resource. The avoided costs of water  
19 treatment were estimated based on the mean cost of water treatment in France (0.46-0.8 €/m<sup>3</sup> depending on  
20 treatment types) (Bommelaer and Devaux 2011). According to local stakeholders, since the DWSZ is already  
21 crossed by a large water pipe that transports surface water from the Verdon River to the coast (i.e. the *Canal de*  
22 *Provence*), a straightforward alternative if the aquifer was no longer able to provide enough good-quality water  
23 would be to resort to the water provided by the *Canal de Provence*. Considering that the costs of connecting to  
24 this pipe are negligible, the avoided costs of interconnecting with an alternative resource were estimated by  
25 directly comparing water prices for consumers that are currently supplied by the aquifer with those that are  
26 currently supplied by the *Canal de Provence*. The assessment was undertaken taking into account differences in  
27 water utility management (direct public management or public service concession). All assessments accounted  
28 for technical efficiencies of local drinking water networks.

### 29 *Fishing*

1 Fishing is practiced for recreational purposes, mainly on the Caramy and Issole Rivers that are fed partly by the  
2 DWSZ groundwater. Through their role in low water replenishment, groundwater resources contribute  
3 significantly to the sustainability of the surrounding environment which favors fish species development and  
4 related fishing activities. [We assume that groundwater degradation would strongly compromise these activities.](#)  
5 According to local angling associations, 2,332 anglers are regularly practicing on the DWSZ. The market value  
6 of the benefits driven from recreational fishing is estimated based on fishing-related expenditures incurred by  
7 anglers (Toivonen et al. 2004). Details of expenditures were gathered from six local angling associations. They  
8 depend on the type of fishing permit subscribed (e.g. adult, child, woman, annual, daily) whose cost varies from  
9 5 to 69€/year, the share of members actually practicing on the DWSZ (the area covered by each association  
10 being larger than the DWSZ) and additional expenditures for equipment, food and transportation, estimated in  
11 the region to 273 €/angler/year according to a survey carried out in 2012 by the Departmental Angling  
12 Federation.

### 13 *Hunting*

14 Big-game hunting is practiced during shooting parties for recreational purposes. According to local hunting  
15 associations, about 400 hunters are regularly practicing on the DWSZ. Related expenditures are used to assess  
16 the market value of hunting activities. They include a national hunting license (300€/year), hunting rights  
17 delivered by local hunting societies whose prices range from 70€/year for local residents to 120€/year for non-  
18 residents, and additional expenditures for hunting dogs, equipment, food and transportation (1,200  
19 €/hunter/year).

### 20 *Speleology*

21 The DWSZ attracts speleologists drawn by its numerous cavities (mainly caves and abysses), as well as two  
22 local remarkable sites. [Speleological activities have strong links with scientific research activities in  
23 hydrogeology aiming at better understanding the functioning of karst aquifers.](#) Approximately 50 speleologists  
24 are regularly practicing on the DWSZ (1 to 3 trips per month). Expenditures include the annual membership to  
25 the National Federation of Speleology (115€/member/year), the membership to a local association (5 to  
26 30€/member/year) and additional expenses for equipment (1,000€/member renewed every 5 years) and food (5  
27 €/trip).

### 28 *Nature walks and cultural heritage*

1 Although located in the vicinity of the Sainte-Baume national forest, the DWSZ lacks infrastructures to attract  
2 overnight visitors (one museum, three hiking trails, one bed and breakfast, one restaurant and two bars). Visitors  
3 are mainly local day-tripper practicing nature walks through the forest. In the absence of accurate visitor  
4 counting, the frequentation of the DWSZ has been estimated by applying a mean visitor rate to the 3,600 ha of  
5 public forests that are accessible to visitors. Two hypotheses were used. The mean visitor rate of forests in  
6 France (58 visitors/ha/year) (Chevassus-au-Louis 2009) was first used, resulting in an estimated 212 000  
7 visitors/year on the DWSZ. This rate was then halved in order to account for the existence of substitutes  
8 (Gomez-Baggethun and Barton 2013) and the relative smaller attractiveness of the DWSZ compared to most  
9 French forests, resulting in an estimated 106 000 visitors/year on the DWSZ.

10 Two economic valuation methods were then applied. First, the results of a survey of visitor expenditures carried  
11 out on local day-trippers in a remarkable site located nearby (estimated to 6.5 €/visitor by Réseau des Grands  
12 Sites de France, 2010) were used to assess the expenditures of hikers on the DWSZ. It was then compared to the  
13 results of a larger survey undertaken in France to assess travel costs incurred by forest walkers (estimated to  
14 7.5€/visitor by (IFEN 2005).

### 15 **3.5. Stakeholder workshop**

16 Finally, we organized a half-day workshop in November 2016 in order to present and put into debate the results  
17 of the assessment. The workshop gathered 25 local stakeholders (including municipalities, environmental  
18 associations, state representatives, water agency, and land managers). [The participation of stakeholders having a  
19 good local knowledge was important to validate the data and assumptions, and to debate the results of the  
20 monetary valuation with their own perception of the ecosystem services.](#) We were particularly interested in  
21 understanding how participants perceived the overall framework for ecosystem services valuation and the ability  
22 of the proposed approach to facilitate the protection of DWSZ.

23 The workshop followed four main sessions, with alternating periods of presentation, completion of individual  
24 questionnaires and collective debates. First, we presented issues related to the protection of the DWSZ both in  
25 and around the study area, the objective of the workshop and the global methodological framework. Participants  
26 were then asked to fill out their individual questionnaire with information about their level of knowledge  
27 regarding the DWSZ and the concept of ecosystem services. They also had to identify, from a general reference  
28 list, the services they perceived as likely to be provided by the study area. Then, the 13 ecosystem services  
29 identified as relevant for valuation were presented and characterized. Again, participants were asked to rate the

1 13 services according to their level of presence (from 1 to 5) and the importance of their preservation (from 1 to  
2 5). Thirdly, we detailed the valuation of nine ecosystem services, in terms of data and methods. Participants  
3 could then compare and debate the results of the economic assessment in light of their own perceptions. After the  
4 concluding session, participants were asked to express themselves about the relevance and the potential  
5 facilitating role of the proposed valuation approach to protect DWSZ, its level of complexity, and the step at  
6 which the approach is the most useful. The three first degrees of ecosystem services assessment and  
7 appropriation proposed by Ten Brink (2011) were used to delineate each step: 1° identification, 2°  
8 characterization / quantification, 3° monetary valuation.

Table 1. Main characteristics of the ecosystem services assessment

<b>Ecosystem services</b>	<b>Valuation methods</b>	<b>Indicators</b>	<b>Sources (data scale)</b>
Wood production	Market prices	Surfaces per type of tree species Proprietorship of parcels Share of woodlands exploited for wood production per type of proprietorship Annual growth rates of trees Stumpage price for tree stands per outlets	Corine Land Cover (1) National Forest Office (2) Observatory of the Mediterranean Forest (3)  National Forest Office (2) Centers of Forests Property (1,2)
Agricultural production	Market prices	Surfaces per type of agricultural activities Yields per hives Income of beekeeping production Gross operating profits	Corine Land Cover (1) / Chamber of Agriculture (1) Chamber of Agriculture (1) Union of French Apiculture (4) Agricultural census (1) / French Livestock Institute (3)
Carbon sequestration and storage	Market prices Social cost of carbon	Woodlands and grasslands surfaces Net annual growth rate of trees Carbon sequestration coefficients Share of carbon stored above and below ground Share of carbon stored over the long-term Prices of CO <sub>2</sub> Emission Allowances Social cost of carbon reference value	Corine Land Cover(1) National Forest Office (2) / National Institute of Geographic and Forest Information (3) Loustau (2004) (4) / Puydarrieux and Devaux (2013) (4) Dupouey et al. (1999) (4) Chevassus-au-Louis (2009) (4) European Energy Exchange AG (4) Quinet (2008) (4)
Flood protection	Replacement cost	Non-artificialized areas Available water storage capacity Mean cost of dams	Corine Land Cover (1) BRGM (2) Bouscasse et al. (2012) (4)
Water cycle regulation	Avoided costs of water treatment Avoided costs of an interconnection	Volume abstracted for drinking water supply Mean cost of water treatment Water prices	Water utilities (1) Bommelaer and Devaux (2011) (4) Water utilities (1)
Fishing	Spending of practitioners	Number of practitioners Expenditures of practitioners	Angling Associations (1) Angling Associations (1)
Hunting	Spending of practitioners	Number of practitioners Expenditures of practitioners	Hunting Societies (1) Hunting Societies (1)
Speleology	Spending of practitioners	Number of practitioners	Federation of Speleology (1)



<b>Ecosystem services</b>	<b>Valuation methods</b>	<b>Indicators</b>	<b>Sources (data scale)</b>
		Expenditures of practitioners	Federation of Speleology (1)
Nature walks and cultural heritage	Benefit transfer from visitor spending Benefit transfer from the travel cost method	Number of practitioners Expenditures of practitioners Travel expenditures of practitioners	Chevassus-au-Louis (2009) (4) Réseau des Grands Sites de France (2010) (5) IFEN (2005) (5)

1 – DWSZ data. 2 – Local expert knowledge. 3 – Regional data. 4 – National data. 5 – Benefit transfer.



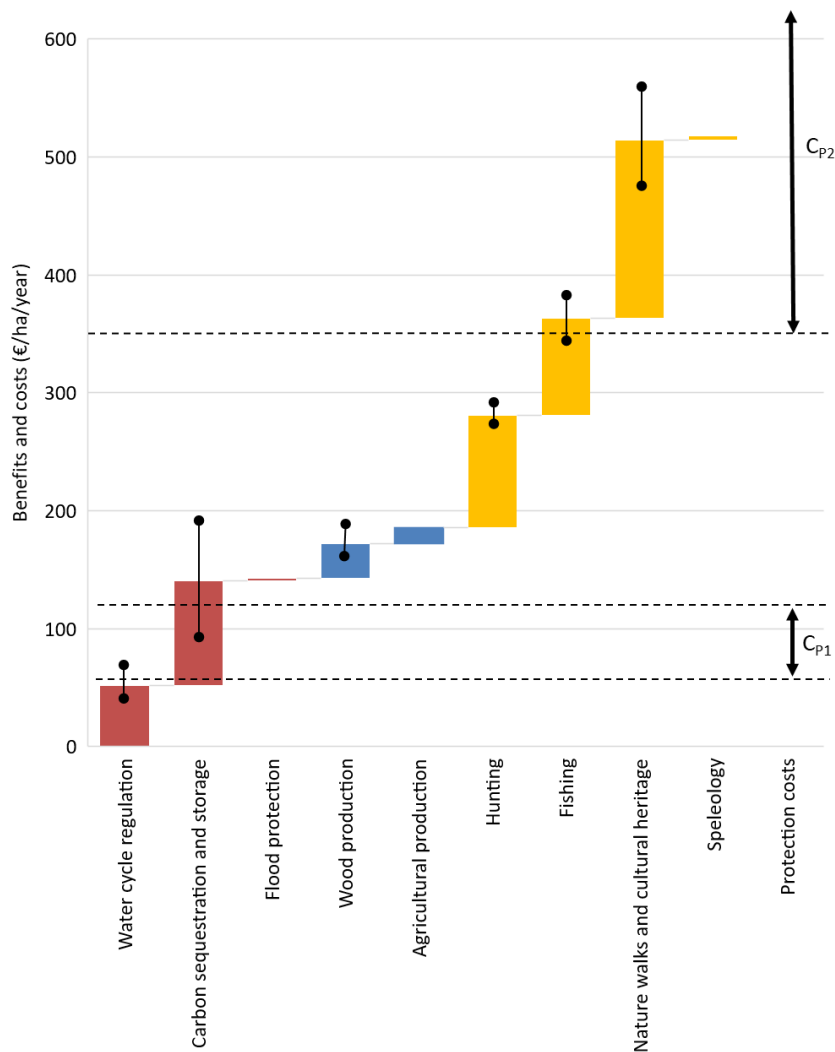
1 These benefits can be compared to the costs of DWSZ protection that can be captured using either the cost of  
2 agri-environmental measures or the opportunity cost of urban development. The cost of the French agri-  
3 environment climate scheme for the conservation of grasslands and pastoral systems range between 58 and 116  
4 €/ha/year (MAAF 2015). This cost is higher than the benefits provided by the water cycle regulation service  
5 alone. These estimates can also be balanced with the opportunity costs of urban development, which are the  
6 benefits that local communities would have to forgo in order to preserve the DWSZ. Due to demographic  
7 growth, the next best land-use alternative in the Sainte-Baume area is urban development. Net revenues from  
8 urbanization depend upon the market value of the real estate on the DWSZ, which can be roughly approximated  
9 using the price difference between woodland and building land in the area (McDonald 2015). According to local  
10 estimates (EPTB<sup>3</sup>, SAFER<sup>4</sup>), the mean value of woodland is about 340 times lower than the mean value of  
11 building land. Considering that the rental value of building land is 5% (Sutton and Anderson 2016), the net  
12 annual revenues from converting woodland to building land are estimated to 70 k€/ha/year. With an annual rate  
13 of urbanization ranging between 2 and 5.2%<sup>5</sup>, urban areas within the DWSZ are expected to expand on an area  
14 of 123 to 214 ha up to 2030. This would result in an increase of the land value ranging from 2.6 to 9 M€/year  
15 (i.e. between 350 and 1220€/ha/year on average on the DWSZ). This cost - that can be used as an indicator of the  
16 protection cost – is significantly higher than the benefits provided by the water cycle regulation alone. Such  
17 results tend to confirm that when resources are not or only little used for human consumption, results obtained  
18 with conventional approaches focusing mainly on water-related benefits are not likely to outweigh the costs of  
19 groundwater protection. However, when expanding the range of benefits so as to account for all the co-benefits  
20 of DWSZ protection, findings may be reversed (Figure 2).

---

<sup>3</sup> <http://www.statistiques.developpement-durable.gouv.fr/donnees-ligne/r/enquete-prix-terrains-batir-eptb.html>

<sup>4</sup> <http://www.safer.fr/indicateur-2016-marche-forets-france.asp>

<sup>5</sup> Mean rate of urbanization experienced from 1990 to 2012 by municipalities with less than 3% of urban areas in 1990 and respectively located in the outer suburbs of Marseille and Toulon coastal metropolis



1

2 Figure 2. Estimated cumulative benefits and comparison with the cost of DWSZ protection. CP1: Cost for the  
 3 conservation of grassland and pastoral systems, CP2: Opportunity cost of urban development (up to 1220  
 4 €/ha/year)

5 ***Informative use of monetary valuation***

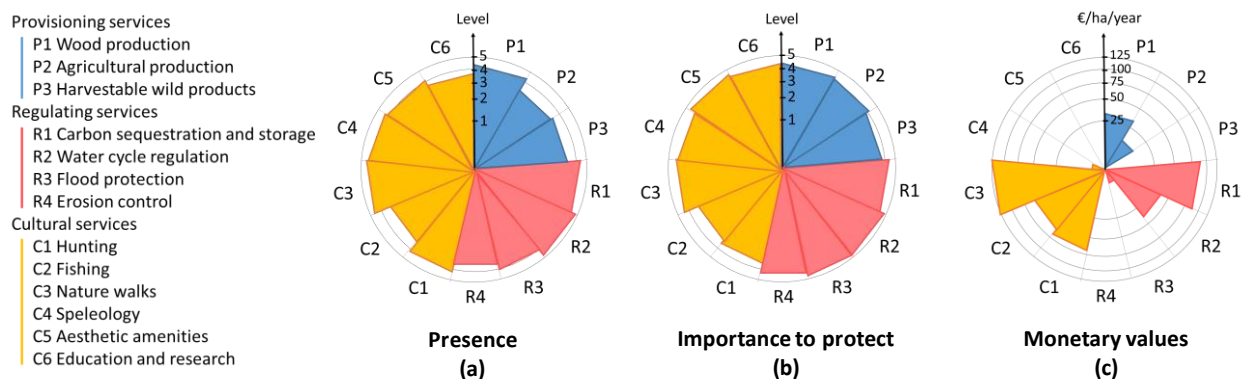
6 We presented these results to local stakeholders during a workshop. Overall, participants confirmed the  
 7 relevance of the proposed approach for highlighting the benefits of protecting DWSZ. A majority considered that  
 8 the approach could help raising awareness on the protection of DWSZ (86%), bring together stakeholders with  
 9 different interests (84%), bridge the gap between environmental issues (76%), and help implementing protection  
 10 actions (62%)<sup>6</sup>.

<sup>6</sup> Participants were asked to rate on an individual questionnaire the potential role of the proposed approach for four issues (from 1: not at all to 5 totally). Percentages represent the number of participants (out of 21) answering 4 or 5.

1 When asked to choose the step at which the approach is the most useful, all participants expressed that the  
2 identification of ecosystem services alone was not sufficient. Most participants considered the characterisation  
3 and monetary valuation steps as the most useful (29% and 43% respectively, with an additional 10% of  
4 participants that could not choose between these two steps). Such results are in line with Costanza et al. (2017)  
5 who state *“The decisions we make as a society about ecosystems imply valuations (although not necessarily*  
6 *expressed in monetary terms)”*. Interestingly, 19% of the participants highlighted that the monetary valuation  
7 step by itself was not sufficient. They argued that the approach should go further. For instance, they  
8 recommended using the methodological framework to compare the benefits resulting from different future land-  
9 use scenarios in order to help selecting and implementing protection actions.

10 Yet, participants also emphasized the limitations of monetary valuation. In particular, the results of the  
11 questionnaire enabled pinpointing differences between (a) stakeholders’ awareness of the ecosystem services  
12 provided by the DWSZ, (b) the importance they attach to their conservation, and (c) the value captured by the  
13 monetary valuation (Figure 3). The divergence between perceptions and monetary values results from two sets of  
14 explanations. First, due to missing data, only nine of the thirteen ecosystem services that were initially identified  
15 by stakeholders were eventually assessed. As a result, the values of some services identified as very important by  
16 stakeholders (harvestable wild products, erosion control, aesthetic amenities and education and research) are not  
17 included in the overall economic estimate. Thus, it should be noted that the results of the monetary assessment  
18 provide only partial insights into the overall value of the benefits of protecting the DWSZ. **Monetary results**  
19 **would benefit from being completed by additional valuation for the missing services.** Second, participants  
20 generally granted high and relatively **homogeneous** scores to the levels of presence and the importance of  
21 services, in comparison with the range of monetary values. As a result, some services with low monetary  
22 estimates are considered as very present on the study area and important to protect (e.g., flood protection,  
23 speleology). Such differences may be interpreted as knowledge gap and thus **call for** information and awareness  
24 campaigns. This can also reflect that stakeholders struggle to discriminate between ecosystem services when  
25 judgments are based on own perceptions, hence the need for scientifically grounded tools and assessment  
26 methods enabling to compare services based on objective criteria. They also reveal that the proposed monetary  
27 valuation **does** not account for some very important socio-cultural preferences, such as social welfare related to  
28 non-use values. Such results highlight that monetary valuation is only part of the way, and that *“valuation*  
29 *approaches that target single value-types, be it economic, ecological or socio-cultural values, can only represent*  
30 *part of the society and its worldviews, interests and preferences”* (Jacobs et al. 2018). They claim for articulating

1 monetary valuation with socio-cultural valuation methods (Martin-Lopez et al. 2012; 2014), in order to better  
 2 elicit stakeholders' preferences.



3  
4

5 Figure 3. Assessment of (a) the level of presence, (b) the importance to protect and (c) the monetary values of 13  
 6 services identified on the DWSZ. Note: (a) average presence level based on the answers of 22 workshop  
 7 participants (from 1: not at all to 5: very present); (b) average importance to protect level based on the answers  
 8 of 22 workshop participants (from 1: not at all to 5: very important); (c) only nine services (out of 13) were  
 9 monetary assessed; values are depicted on a different scale (from 0 to 125 €/ha/year).

10 **5. Conclusion and perspectives**

11 The valuation of ecosystem services can have many potential uses, at multiple time and space scales, from  
 12 simply raising awareness to detailed analysis of various policy choices and scenarios (Costanza et al. 2017). This  
 13 article demonstrates the relevance of valuing a diversity of ecosystem services for raising awareness on the need  
 14 to protect strategic groundwater resources at local scale, especially when stakeholders are involved in the  
 15 assessment process. It proposes a promising approach to enhance the protection of DWSZ for the future,  
 16 especially when conventional economic approaches face limitations. It highlights that any relevant rationale  
 17 aiming at highlighting the interest of preserving good-quality groundwater resources should bring to light the  
 18 multiple co-benefits provided by maintaining in good condition existing ecosystems. *Although monetary  
 19 valuation provides only partial insights, it may be sufficient to tip the balance in favor of conservation. Results  
 20 also suggest that monetary valuation would benefit from being combined with other valuation methods to assess  
 21 the full set of values related to ecosystem services (Costanza et al. 2017; Jacobs et al. 2018; Kenter 2016).*

22 From a methodology perspective, this research proposes a low-cost and time-efficient method to assess the  
 23 overall value of a set of diversified ecosystem services. The valuation methods and level of precision required  
 24 are appropriate when using the valuation of ecosystem services for raising awareness (Costanza et al. 2017).

1 **They also make a case for costs assessment.** Primarily based on local indicators and data, it also allows resorting  
2 to expert knowledge or regional and national proxies as surrogates to approximate indicators of ecosystem  
3 functions and processes when local information is lacking. This enables locally grounding the assessment within  
4 a local context, which contrasts with some WFD economic assessments that are performed mechanically, rarely  
5 involve local stakeholders in the process, and as a result, **poorly** reflect local specificities and concerns of  
6 stakeholders (Feuillette et al. 2015). Future methodological perspectives include (1) applying the approach to  
7 other DWSZ depicting contrasted land use types (e.g., urban) in order to test its operational relevance in other  
8 environmental, economic and socio-cultural contexts, and (2) comparing future alternative land use and  
9 management scenarios.

10 From a policy perspective, the approach sets the basis to construct coalitions between natural resources  
11 protection policies. As protecting strategic groundwater resources requires the development of dedicated policy  
12 instruments, granting a monetary value to its benefits may help envisaging innovative cross-funding instruments  
13 (Abell et al. 2017) and building bridges with the instruments that are currently implemented for biodiversity  
14 conservation. This is all the more relevant since such areas are likely to multiply over the next century.

## 15 **Acknowledgements**

16 This work was financially supported by the French Rhône Méditerranée Corse Water Agency.

## 17 **References**

18 Abdalla CW (1994) Groundwater Values from Avoidance Cost Studies: Implications for Policy and Future  
19 Research. *American Journal of Agricultural Economics* 76:1062-1067

20 Abell R, Asquith N, Boccaletti G, Bremer L, Chapin E, Erickson-Quiroz A, Higgins J, Johnson J, Kang S,  
21 Karres N, Lehner B, McDonald R, Raeppele J, Shemie D, Simmons E, Sridhar A, Vigerstøl K, Vogl A,  
22 Wood S (2017) *Beyond the Source: The Environmental, Economic and Community Benefits of Source*  
23 *Water Protection*, The Nature Conservancy, Arlington, VA, USA. Available on  
24 <https://global.nature.org/content/beyond-the-source?src=r.global.beyondthesource>

25 Aguilar FX, Obeng EA, Cai Z (2018) Water quality improvements elicit consistent willingness-to-pay for the  
26 enhancement of forested watershed ecosystem services. *Ecosystem Services* 30 :158-171.  
27 doi:10.1016/j.ecoser.2018.02.012

- 1 Arrouays D, Balesdent J, Germon JC, Jayet PA, Soussana JF, Stengel P (2002) Stocker du carbone dans les sols  
2 agricoles de France? Synthèse du rapport d'expertise réalisé par l'INRA à la demande du Ministère de  
3 l'Ecologie et du Développement Durable.
- 4 Barraqué B, Viavattene C (2009) Eau des villes et Eau des champs. *Économie rurale* 310: 5-21. doi :  
5 10.4000/economierurale.708
- 6 Bateman IJ, Harwood AR, Mace GM, Watson RT, Abson DJ, Andrews B, Binner A, Crowe A, Day BH,  
7 Dugdale S, Fezzi C, Foden J, Hadley D, Haines-Young R, Hulme M, Kontoleon A, Lovett AA, Munday  
8 P, Pascual U, Paterson J, Perino G, Sen A, Siriwardena G, van Soest D, Termansen M (2013) Bringing  
9 Ecosystem Services into Economic Decision-Making: Land Use in the United Kingdom. *Science* 341  
10 (6141): 45-50. doi: 10.1126/science.1234379
- 11 Blanchard L, Vira B, Briefer L (2015) The lost narrative: Ecosystem service narratives and the missing Wasatch  
12 watershed conservation story. *Ecosystem Services* 16: 105-111. doi :10.1016/j.ecoser.2015.10.019
- 13 Bommelaer O, Devaux J (2011) Coûts des principales pollutions agricoles de l'eau. Etudes et documents  
14 n°52:34. Commissariat Général au Développement Durable, Paris
- 15 Bouscasse H, Defrance P, Duprez C, Strosser P, Beley Y, Morardet S (2012) Evaluation économique des  
16 services rendus par les zones humides. Le cas de la moyenne vallée de l'Oise.  
17 Collection « Études et documents » du Service de l'Économie, de l'Évaluation et de l'Intégration du Dé  
18 veloppement Durable (SEEIDD) du Commissariat Général au Développement Durable (CGDD), 84p.
- 19 Bouwma I, Schleyer C, Primmer E, Winkler KJ, Berry P, Young J, Carmen E, Špulerová J, Bezák P, Preda E,  
20 Vadineanu A (2018) Adoption of the ecosystem services concept in EU policies. *Ecosystem Services*.  
21 doi: <https://doi.org/10.1016/j.ecoser.2017.02.014>
- 22 Brauman KA, Daily GC, Duarte TK, Mooney HA (2007) The nature and value of ecosystem services: an  
23 overview highlighting hydrologic services. *Annual Review of Environment and Resources* 32:67-98.  
24 doi:10.1146/annurev.energy.32.031306
- 25 Castro AJ, Martín-López B, López E, Plieninger T, Alcaraz-Segura D, Vaughn CC, Cabello J (2015) Do  
26 protected areas networks ensure the supply of ecosystem services? Spatial patterns of two nature reserve  
27 systems in semi-arid Spain. *Applied Geography* 60:1-9. doi:10.1016/j.apgeog.2015.02.012.



- 1 CBD (2010) COP 10 – Tenth Meeting of the Conference of the Parties to the Convention on Biological  
2 Diversity. Nagoya, Japan 18–29 October 2010. Decision X/2. Strategic Plan for Biodiversity 2011–  
3 2020 and the Aichi Biodiversity Targets. United Nations Environment Programme.  
4 <http://www.cbd.int/sp/targets/>
- 5 Chevassus-au-Louis B (2009) Approche économique de la biodiversité et des services liés aux écosystèmes.  
6 Contribution à la décision publique. Série rapports et documents, Centre d'Analyse Stratégique, La  
7 documentation française, Paris, 399 p.
- 8 Chichilnisky G, Heal G (1998) Economic returns from the biosphere, *Nature* 391: 629-630. doi:10.1038/35481
- 9 Costanza R, de Groot R, Braat L, Kubiszewski I, Fioramonti L, Sutton P, Farber S, Grasso M (2017) Twenty  
10 years of ecosystem services: How far have we come and how far do we still need to go? *Ecosystem*  
11 *Services* 28:1-16. doi:10.1016/j.ecoser.2017.09.008
- 12 de Groot R, Brander L, van der Ploeg S, Costanza R, Bernard F, Braat L, Christie M, Crossman N, Ghermandi  
13 A, Hein L, Hussain S, Kumar P, McVittie A, Portela R, Rodriguez LC, ten Brink P, van Beukering P  
14 (2012) Global estimates of the value of ecosystems and their services in monetary units. *Ecosystem*  
15 *Services* 1(1): 50-61. doi:10.1016/j.ecoser.2012.07.005
- 16 Dupouey JL, Pignard G, Badeau V et al. (2002) Stocks et flux de carbone dans les forêts françaises. *Forêt*  
17 *Wallone* 57 : 6-19
- 18 European Commission (2012) A Blueprint to Safeguard Europe's Water Resources. Communication from the  
19 Commission to the European Parliament, the Council, the European Economic and Social Committee  
20 and the Committee of the Regions. [http://eur-lex.europa.eu/legal-](http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52012DC0673)  
21 [content/EN/TXT/?uri=CELEX:52012DC0673](http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52012DC0673)
- 22 Feuillette S, Levrel H, Blanquart S, Gorin O, Monaco G, Penisson B, Robichon S (2015) Évaluation monétaire  
23 des services écosystémiques. Un exemple d'usage dans la mise en place d'une politique de l'eau en  
24 France. *Natures sciences sociétés* 23(1): 14-27
- 25 Fisher B, Turner RK, Morling P (2009) Defining and classifying ecosystem services for decision making.  
26 *Ecological Economics* 68:643-653. doi:10.1016/j.ecolecon.2008.09.014

- 1 Gómez-Baggethun E, Barton DN (2013) Classifying and valuing ecosystem services for urban planning.  
2 Ecological Economics 86:235-245. doi:10.1016/j.ecolecon.2012.08.019
- 3 Grolleau G, McCann LMJ (2012) Designing watershed programs to pay farmers for water quality services: Case  
4 studies of Munich and New York City. Ecological Economics 76:87-94.  
5 doi :10.1016/j.ecolecon.2012.02.006
- 6 Haines-Young R, Potschin MB (2018) Common International Classification of Ecosystem Services (CICES)  
7 V5.1 and Guidance on the Application of the Revised Structure. Available from [www.cices.eu](http://www.cices.eu)
- 8 Hérivaux C, Grémont M (2015) Caractérisation des bénéfices économiques liés à la préservation des eaux  
9 souterraines: le cas des zones de sauvegarde pour l'alimentation en eau potable. BRGM/RP-63859-FR:  
10 236. <http://infoterre.brgm.fr/rapports/RP-63859-FR>
- 11 Hérivaux C, Rinaudo JD (2016) Integrated assessment of economic benefits of groundwater improvement with  
12 contingent valuation. In: Jakeman A.J., Barreteau O., Hunt R.J., Rinaudo JD., Ross A. (eds) Integrated  
13 Groundwater Management. Springer, pp 519-549. doi:10.1007/978-3-319-23576-9\_21.
- 14 IFEN (2005) Les multiples valeurs de la forêt française, Les données de l'environnement, numéro 105, 4p.
- 15 Institut de l'Élevage (2012) Résultats Technico-économiques 2012, Systèmes bovins en PACA et Rhône-Alpes,  
16 actualisation 2011.
- 17 Institut Forestier National (2012) La forêt en chiffres et en cartes, 2012.
- 18 IPCC (2014) Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth  
19 Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K.  
20 Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.
- 21 Jacobs S, Martín-López B, Barton DN, Dunford R, Harrison PA, Kelemen E, Saarikoski H, Termansen M,  
22 García-Llorente M, Gómez-Baggethun E, Kopperoinen L, Luque S, Palomo I, Priess JA, Rusch GM,  
23 Tenerelli P, Turkelboom F, Demeyer R, Hauck J, Keune H, Smith R (2018) The means determine the  
24 end – Pursuing integrated valuation in practice. Ecosystem Services 29:515-528.  
25 doi:10.1016/j.ecoser.2017.07.011

- 1 Jimenez Cisneros BE, Oki T, Arnell NW, Benito G, Cogley JG, Doll P, Jiang T, Mwakalila SS (2014)  
2 Freshwater resources. In: Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE,  
3 Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S,  
4 Mastrandrea PR, White LL (eds.) Climate Change 2014: Impacts, Adaptation and Vulnerability. Part A:  
5 Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the  
6 Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp. 229-269
- 7 Johnson KA, Dalzell BJ, Donahue M, Gourevitch J, Johnson DL, Karlovits GS, Keeler B, Smith JT (2016)  
8 Conservation Reserve Program (CRP) lands provide ecosystem service benefits that exceed land rental  
9 payment costs. *Ecosystem Services* 18:175-185. doi: 10.1016/j.ecoser.2016.03.004
- 10 Keeler BL, Polasky S, Brauman KA, Johnson KA, Finlay JC, O'Neill A, Kovacs K, Dalzell B (2012) Linking  
11 water quality and well-being for improved assessment and valuation of ecosystem services. *Proceedings*  
12 *of the National Academy of Sciences of the United States of America*. doi: 10.1073/pnas.1215991109
- 13 Kenter JO (2016) Editorial: Shared, plural and cultural values. *Ecosystem Services* 21:175-183.  
14 doi:10.1016/j.ecoser.2016.10.010
- 15 Liqueste C, Udias A, Conte G, Grizzetti B, Masi F (2016) Integrated valuation of a nature-based solution for  
16 water pollution control. Highlighting hidden benefits. *Ecosystem Services* 22:392-401.  
17 doi:10.1016/j.ecoser.2016.09.011
- 18 Loustau (2004) Séquestration du Carbone dans les grands écosystèmes forestiers en France. Quantification,  
19 spatialisaton, vulnérabilité et impacts de différents scénarios climatiques et sylvicoles. Rapport Final du  
20 Projet CARBOFOR, Juin 2004.
- 21 MAAF (2015) MAEC systèmes herbagers et pastoraux (logique de maintien de pratiques existantes), Cap sur la  
22 PAC 2015-2020, Ministère de l'Agriculture, de l'Agroalimentaire et de la Forêt, Paris.  
23 [http://agriculture.gouv.fr/maec-les-nouvelles-mesures-agro-environnementales-et-climatiques-de-la-](http://agriculture.gouv.fr/maec-les-nouvelles-mesures-agro-environnementales-et-climatiques-de-la-pac-2015)  
24 [pac-2015](http://agriculture.gouv.fr/maec-les-nouvelles-mesures-agro-environnementales-et-climatiques-de-la-pac-2015)
- 25 Martín-López B, Gómez-Baggethun E, García-Llorente M, Montes C (2014) Trade-offs across value-domains in  
26 ecosystem services assessment. *Ecological Indicators* 37:220-228. doi:10.1016/j.ecolind.2013.03.003

- 1 Martín-López B, Iniesta-Arandia I, García-Llorente M, Palomo I, Casado-Arzuaga I, Amo DGD et al. (2012)  
2 Uncovering Ecosystem Service Bundles through Social Preferences. PLoS ONE, 7(6), e38970. doi:  
3 10.1371/journal.pone.0038970
- 4 McDonald RI (2015) The effectiveness of conservation interventions to overcome the urban–environmental  
5 paradox. Annals of the New York Academy of Sciences 1355:1-14. doi: 10.1111/nyas.12752
- 6 MEA (2005) Millennium Ecological Assessment. Ecosystem and Human Well-being: A framework for  
7 Assessment. A Report of the Conceptual Framework Working Group of the Millennium Ecosystem  
8 Assessment. Island Press, Washington
- 9 MEDDE (2013) Synthèse du projet Explore 2070: Hydrologie souterraine. Ministère de l'Ecologie, du  
10 Développement Durable et de l'Energie, Paris.  
11 [http://www.onema.fr/sites/default/files/pdf/RE\\_Explore2070\\_4pages\\_Eaux\\_souterraines.pdf](http://www.onema.fr/sites/default/files/pdf/RE_Explore2070_4pages_Eaux_souterraines.pdf)
- 12 Nel JL, Le Maitre DC, Roux DJ, Colvin C, Smith JS, Smith-Adao LB, Maherry A, Sitas N (2017) Strategic  
13 water source areas for urban water security: Making the connection between protecting ecosystems and  
14 benefiting from their services. Ecosystem Services 28(B):251-259. doi: 10.1016/j.ecoser.2017.07.013
- 15 Nelson NM, Loomis JB, Jakus PM, Kealy MJ, von Stackelburg N, Ostermiller J (2015) Linking ecological data  
16 and economics to estimate the total economic value of improving water quality by reducing nutrients.  
17 Ecological Economics 118:1-9. doi:10.1016/j.ecolecon.2015.06.013
- 18 Ninan KN, Inoue M (2013) Valuing forest ecosystem services: What we know and what we don't. Ecological  
19 Economics 93:137-149. doi :10.1016/j.ecolecon.2013.05.005
- 20 OFME (2003) Les espaces forestiers en Provence-Alpes-Côte d'Azur, Fiche n°27. Observatoire de la Forêt  
21 Méditerranéenne, Gardanne, France.
- 22 Pivot J-M, Aznar O (2000) Acquisition foncière et environnement : le cas de la protection d'un captage d'eau  
23 potable. Économie rurale 260 :135-141
- 24 Poe GL, Boyle KJ, Bergstrom JC (2000) A meta-analysis of contingent values for groundwater quality in the  
25 United States. 2000 Annual meeting, July 30-August 2, Tampa, FL 21871, American Agricultural  
26 Economics Association (New Name 2008: Agricultural and Applied Economics Association)

- 1 Puydarrieux P, Devaux J (2013) Quelle évaluation économique pour les services écosystémiques rendus par les  
2 prairies en France métropolitaine ? n°89 de la collection "Etudes et documents" du SEEIDD du CGDD,  
3 40p.
- 4 Quinet A (2008) La valeur tutélaire du carbone, Série rapports et documents, N°16, Centre d'Analyse  
5 Stratégique, La documentation française, Paris, 424p.
- 6 Quinet E (2013) L'évaluation socioéconomique des investissements publics, Rapport de la mission présidée par  
7 Emile Quinet, Série Rapports et documents, Commissariat général à la stratégie et à la prospective,  
8 Paris, 352 p.
- 9 Réseau des Grands Sites de France (2010) Evaluation des avantages économiques liés au Grand Site Sainte-  
10 Victoire, Réseau des grands sites de France, Paris, 26p.
- 11 Rinaudo JD, Arnal C, Blanchin R, Elsass P, Meilhac A, Loubier S (2005) Assessing the cost of groundwater  
12 pollution: the case of diffuse agricultural pollution in the Upper Rhine valley aquifer. *Water Science  
13 and Technology* 52:153-162
- 14 Smith M, Cross K, Paden M, Laban P (2016) *Spring: managing groundwater sustainably*. IUCN, Gland,  
15 Switzerland. <http://dx.doi.org/10.2305/IUCN.CH.2016.WANI.8.en>
- 16 Sutton PC, Anderson SJ (2016) Holistic valuation of urban ecosystem services in New York City's Central Park.  
17 *Ecosystem Services* 19:87-91. doi: 10.1016/j.ecoser.2016.04.003
- 18 ten Brink P (2011) *The economics of ecosystems and biodiversity in national and international policy making*.  
19 Routledge.
- 20 Toivonen AL, Roth E, Navrud S, Gudbergsson G, Appelblad H, Bengtsson B, Tuunainen P (2004) The  
21 economic value of recreational fisheries in Nordic countries. *Fisheries Management and Ecology* 11:1-  
22 14. doi:10.1046/j.1365-2400.2003.00376.x
- 23 Venkatachalam L (2004) The contingent valuation method: a review. *Environmental Impact Assessment Review*  
24 24(1): 89-124. doi:10.1016/S0195-9255(03)00138-0
- 25 Vlachopoulou M, Coughlin D, Forrow D, Kirk S, Logan P, Voulvoulis N (2014) The potential of using the  
26 Ecosystem Approach in the implementation of the EU Water Framework Directive. *Science of the Total  
27 Environment* 470–471:684-694. doi:10.1016/j.scitotenv.2013.09.072

1 Wallace KJ (2007) Classification of ecosystem services: Problems and solutions. *Biological Conservation* 139  
2 (3-4): 235-246. doi:10.1016/j.biocon.2007.07.015

3 Wang Y, Atallah S, Shao G (2017) Spatially explicit return on investment to private forest conservation for  
4 water purification in Indiana, USA. *Ecosystem Services* 26:45-57. doi:10.1016/j.ecoser.2017.06.004

5 Watkiss P, Hope C (2011) Using the social cost of carbon in regulatory deliberations. *WIREs Climate Change*  
6 2:886-901. doi: 10.1002/wcc.140

7 WWAP (2015) The United Nations World Water Development Report 2015: Water for a Sustainable World.  
8 United Nations World Water Assessment Programme. UNESCO, Paris

9

10

11