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4 Groundwater Dependent Ecosystems Part II: Ecosystem Services and Management
5 Under Risk of Climate Change and Land Use Intensification
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Abstract

Groundwater in sufficient amounts and of suitable quality is essential for potable water supplies, crop irrigation and healthy habitats for plant and animal biocenoses. The groundwater resource is currently under severe pressure from land use and pollution and there is evidence of dramatic changes in aquifer resources in Europe and elsewhere, despite numerous policy measures on sustainable use and protection of groundwater. Little is known about how such changes affect groundwater dependent ecosystems (GDEs), which include various aquatic and terrestrial ecosystems above ground and inside the aquifer. Future management must take this uncertainty into account. This paper focuses on multiple aspects of groundwater science, policy and sustainable management. Examples of current management methods and practices are presented for selected aquifers in Europe and an assessment is made of the effectiveness of existing policies in practice and of how groundwaters and GDEs are managed in various conditions. The paper highlights a number of issues that should be considered in an integrated and holistic approach to future management of groundwater and its dependent ecosystems.

Keywords: groundwater, ecosystems, management, policy, ecosystem services.

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1. Introduction

Groundwater is undoubtedly one of the greatest providers of life support functions. About 75% of European Union (EU) residents depend on groundwater for their water supply. Although groundwater and groundwater dependent ecosystems (GDEs) are protected by a number of EU directives, national legislation and environmental action programmes to preserve biodiversity, many GDEs in Europe are under threat and degrading (Boulton, 2005; EC 2007a, 2007b). An important threat to groundwater services is the lowering of groundwater levels due to aquifer over-exploitation (abstraction), drainage for agriculture, and dewatering due to infrastructure development and mining. Another important threat is diffuse pollution with nutrients, pesticides and heavy metals (Kløve et al., 2011, this volume).

Public awareness of groundwater is still surprisingly poor. Groundwater receives less attention than surface water because it is not visible and the pollution problems are not as obvious as those in surface waters, e.g. dead fish or algal blooms (Boulton, 2005). The role of groundwater in wetlands, streams and other GDEs is often complex and poorly documented. Furthermore, the possible effects of climate change on GDEs are uncertain, partly due to a lack of rigorous studies. Consequently, it is difficult to provide evidence of causal links between an identified pressure (abstraction, pollution) via an ‘environmental pathway’ to a GDE, given the large variations in residence time, spatial hydrogeological variations and time dependent climatic factors. The GENESIS project was started in 2009 with the goal of bridging some of the knowledge gaps and providing a scientific basis for better future management of groundwater and GDE resources.

In the future management of groundwater resources, GDEs will require special attention (Kvæerner and Kløve, 2006) and future ecological status assessments of GDEs will have to consider how groundwater is connected to these GDEs (Eamus et al., 2006; Paetzold et al., 2010). In addition, various functions of ecosystems will have to be identified in order to obtain the best management option for future groundwater use. This paper reviews past development of the policy framework and theoretical concepts of sustainable use of groundwater and related ecosystem services, and presents practical examples to identify key knowledge gaps and to demonstrate problems in groundwater resource management. Recommendations are given for

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4 integrated groundwater management that takes better account of uncertainty, sustainable use and
5 ecosystem services of GDEs.
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10 11 2. Policy framework 12 13 14

15 2.1 EU Birds and Habitats Directives 16 17

18 International policy relating to the protection of habitats initially started as wetland conservation
19 arising from the Ramsar Convention in 1971, which focused on protecting birds and their
20 habitats. This resulted in the EU Birds Directive in 1979 and later in the EU Habitats Directive in
21 1992 (EC, 1992). The latter Directive meant a shift from species protection to habitat protection,
22 which now forms the cornerstone of Europe's nature conservation policy and the protection of
23 GDE. This Directive is built around two pillars, the Natura 2000 network of protected sites and a
24 strict system for species protection. The Directive protects over 1 000 animal and plant species
25 and over 200 'habitat types' (e.g. special types of forests, meadows, wetlands, etc.) of European
26 importance. The Directive requires Member States to designate Natura 2000 sites. In 2004 the
27 Directive was adopted by 10 new Member States and in 2007 by two additional Member States.
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39 2.2 Water Framework Directive 40 41

42 The European Water Framework Directive (WFD) of 2000 clearly identifies the protection,
43 restoration and enhancement of the water needs of GDEs in article 1a: *'The purpose of this*
44 *Directive is to establish a framework for the protection of inland surface waters, transitional*
45 *water, coastal waters and groundwater which: a) prevents further deterioration and protects and*
46 *enhances the status of aquatic ecosystems and, with regard to their water needs, terrestrial*
47 *ecosystems and wetlands directly depending on the aquatic ecosystems'*(EC, 2000). The WFD is
48 the most substantial part of the EU water legislation and aims to overcome the fragmentation of
49 European water policy. It requires Member States to designate water bodies (surface,
50 groundwater and coastal) and to reach 'good status' for these by establishing River Basin
51 Management Plans (RBMPs), in which specific environmental objectives and programmes of
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4 measures to achieve these are established. The WFD sets groundwater objectives that include
5 obligations towards GDEs. The most important obligations of the WFD and its companion
6 Directive on Groundwater Protection (EC, 2006) in relation to GDEs are to achieve good
7 groundwater status and prevent significant damage to terrestrial ecosystems that directly depend
8 on groundwater bodies (Table 1). The directives should meet the requirements in protected areas as
9 requested specifically under the Habitats and Wild Birds Directives, and take protective or restorative
10 action in the management of GDEs which are included in the register of protected areas (at least the
11 Natura 2000 sites).
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20 Risks to GDEs in terms of both chemical and quantitative status should be assessed (EC, 2010).
21 For each objective, the risks of not meeting that objective must be assessed. The Source-
22 Pathway-Receptor approach to assess these risks has to be applied at different scales, varying
23 from individual dependent surface water or terrestrial ecosystems to aquifer scale.
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29 The WFD identifies the need for protection and restoration of wetlands, but does not provide any
30 specific definition of what a wetland is, nor does it provide details on how wetlands should be
31 used to achieve the WFD objectives. Therefore, the role of wetlands in the WFD is explained
32 further in the WFD Guidance document No. 12 (EC, 2003). This guidance is not legally binding,
33 but is the most up-to-date reference document for European wetland policy (EC, 2007b). It
34 mentions several important WFD provisions in relation to wetlands protection and restoration
35 (Table 1). The Guidance Document outlines the best practices beyond the legal requirements of
36 the WFD (EC, 2007b). It was prepared to assist Member States in wetland protection in the
37 implementation of the WFD, EU nature conservation policy and, in particular, the Habitats and
38 Birds Directives.
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49 The WFD aims to achieve sustainable use of water resources. It integrates key principles in water
50 policy, such as the involvement and participation of stakeholders, management at the basin scale
51 (with implications for administrative change) and integration of the economic dimension of
52 water management. The WFD requires the application of economic principles (e.g. the ‘polluter
53 pays’ principle) and the use of certain methods and tools (e.g. cost-effectiveness analysis), as
54 well as the consideration of economic instruments (e.g. water pricing) to achieve the
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4 environmental objectives and to aid decision-making (WATECO, 2003; Heinz et al., 2007).
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6 However, to date the WFD has not clearly stated the scope that economic analysis should use
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8 (Meyerhoff and Dehnhardt, 2007).
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10 11 12 2.3 Adaptation to climate change 13 14

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16 The EC has recognised that its policy on Natura 2000 is a critical climate change adaptation
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18 measure because biodiversity will be more resilient to climate change if the ecosystems are in a
19
20 healthy state, which in turn is vital to human adaptation to climate change. Human prosperity and
21
22 wellbeing depend on the services that healthy ecosystems supply (EC, 2007a, EC, 2007b, EC,
23
24 2009). The EU recognises that resilience and adaptation will require actions outside the Natura
25
26 2000 network to enhance connectivity and coherence. Facilitating nature's adaptation to climate
27
28 change also involves reducing conventional pressures on biodiversity such as intensification of
29
30 land use, fragmentation of habitats, overexploitation and pollution. In a white paper (EC, 2009),
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32 the EC sets out a framework to reduce the EU's vulnerability to the impact of climate change. It
33
34 mentions that the EU is working with other partner countries in the United Nations Framework
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36 Convention on Climate Change towards a post-2012 climate agreement, which will address
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38 adaptation as well as mitigation. Some actions mentioned in the paper with regard to ecosystems,
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40 biodiversity and water (Table 1).
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44 2.4 Policy and Action plans to stop biodiversity loss 45 46

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48 The European Commission agreed upon an EU biodiversity strategy in 1998 and adopted several
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50 biodiversity action plans to halt biodiversity loss by 2010 (EC, 2007a and 2007b, EU 2009a and
51
52 2009b). These action plans resulted from a push in favour of nature conservation measures by the
53
54 EU Member States. Unlike its predecessors, the latest plan does not suggest ambitious laws to
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56 protect migrating wild birds and natural habitats, but tries to assign responsibilities concerning
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58 the implementation of existing legislation. The latter includes not only the aforementioned
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60 Natura 2000, but also the Common Agriculture Policy and Common Fisheries Policies that have
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4 recently been reformed to take better account of wildlife, plants and forests. Funding has also
5 been devoted to biodiversity research. LIFE is an important financial instrument of the EC for
6 co-funding projects to support the implementation of EU policy and legislation (Oliver et al.,
7
8 2005). The Action Plan identifies four priority areas, namely:
9

- 10 ○ Biodiversity in the EU: Greater commitment from member states to propose, designate,
11 protect and effectively manage sites protected under the Natura 2000 network.
12
- 13 ○ The EU and global biodiversity: Strengthening coherence and synergies between trade and
14 development cooperation.
15
- 16 ○ Biodiversity and climate change: Honouring Kyoto commitments and putting in place more
17 ambitious global emissions targets post-2012.
18
- 19 ○ The knowledge base: Strengthening the European Research Area, its international dimension,
20 research infrastructure, the connection between science and policy and improving
21 comparability of biodiversity data.
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29 In a mid-term assessment of implementation of the EU Biodiversity Action Plan (EU, 2009b),
30 the Council of the EU stressed that biodiversity loss is extremely worrying not only for the
31 important intrinsic value of nature and biodiversity, but also because it results in a decline in
32 ecosystem functions that are essential in providing vital ecosystem services which underpin long-
33 term sustainable development. The positive progress made within the Biodiversity Action Plan is
34 not sufficient to meet the objective, and the Council strongly emphasizes that significant additional
35 efforts are urgently needed to reverse these trends. It highlights the importance of strengthening
36 the integration of biodiversity and ecosystem concerns into relevant policies and the effective
37 implementation of existing EU policies and legislation to address the biodiversity challenge. The
38 Council urges the EC and Member States to complete the terrestrial part of the Natura 2000
39 network by 2010. All available opportunities should be used to strengthen biodiversity
40 conservation in rural development under cross-compliance arising from the health check of the
41 Common Agriculture Policy. Conservation and sustainable use of biodiversity and ecosystem
42 services in the outermost regions of Europe that are not covered by EU nature legislation should
43 also be promoted.
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60 2.5 Policies in practice: Are they sustainable?
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4 Despite these ambitious and promising policies, action plans and co-funded LIFE projects, the
5 state and trends of GDEs and biodiversity are not in line with the objectives. In 2006, the World
6 Conservation Union added some 530 species to its 'red list' of endangered species, illustrating
7 that biodiversity loss is increasing, not slowing down. Environmental organisations such as the
8 World Wildlife Fund and European Environmental Bureau say that there is 'ample evidence' that
9 environmental protection has been 'politically downgraded' to a side role, to the benefit of the
10 Commission's growth and jobs objectives. Greenpeace has pointed out that the EU must not only
11 document and monitor loss of biodiversity, but also review its own destructive policies for their
12 part in the crisis and take the necessary measures to revise them. Unfortunately, EU policy also
13 promotes the increased use of biofuels, which leads to dramatic land consumption, thus
14 counteracting all efforts to protect biodiversity.
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25 Most conservation efforts in aquatic ecosystems focus on surface waters, which is
26 understandable given their public visibility, accessibility and stark evidence of their vulnerability
27 to human impact. Groundwater protection and conservation is less common (Boulton, 2005). The
28 implementation of the WFD is still in quite an early stage, and most of the WFD measures
29 promised in RBMPs focus on reduction of inputs of nutrients from point sources and a more
30 natural design of water courses. At Natura 2000 sites with GDEs that are not designated as water
31 bodies, concrete targets on groundwater and related measures to reach these have generally not
32 been established yet. In its mid-term assessment of implementation of the EU Biodiversity
33 Action Plan (EU 2009a and 2009b), the EU Council noted that about half the species in the
34 European Community and about two-thirds of the habitat types of interest have an inadequate
35 conservation status. Based on this assessment, the EU Committee of the Regions called on the
36 EU, Member States and local and regional authorities to set up a strict system of eco-
37 conditionality for grants and funding. In a policy recommendation, the Committee of the Regions
38 states that the Natura 2000 network sites need to be consolidated in most countries. The poor
39 quality of the scientific reference data undermines any efforts to assess the extent to which such
40 Natura 2000 land sites meet the criteria of the Habitats and Birds Directives. The Committee of
41 the Regions also asks Member States to assume their responsibilities for marine areas and
42 groundwater in this regard and stresses that tailor-made management plans for Natura 2000 sites
43 need to be drawn up and implemented.
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3. Sustainability concepts and methods for groundwater and GDEs

According to the Bruntland Report¹ sustainability refers to as ‘a development, which enables present generations to satisfy their needs without threatening the ability of future generations to satisfy theirs’. For groundwater, sustainability has been regarded as a question of how much can be used compared with recharge. In recent decades resource management has also focused on how to I) prevent pollution inputs, II) keep contaminant concentrations to a safe level, and III) reverse pollution trends. This has been motivated by drinking water standards and human health and by increasing risk of pollution. For GDE management, both water quantity and quality are important to maintain habitat and biodiversity (Kløve et al., 2011, this volume).

3.1 Safe yield concept

The term *safe yield* is an old concept used in efforts to quantify sustainable groundwater resource development. There have been several definitions of the concept of safe yields by different authors (Lee, 1915), considering storage, economic feasibility, water quality and water rights (Alley and Leake, 2004). Todd (1959) broadened the definition of safe yield for groundwater as ‘the amount of water that can be withdrawn from a groundwater basin annually without producing an undesired result’. The concept of considering groundwater resource development as ‘safe’ if the average annual rate of withdrawal does not exceed the average annual rate of natural recharge is usually not as sound as is believed, especially during long-term climatic fluctuations and when GDEs are considered (see Sophocleous, 1997). Groundwater sustainability indicators such as use/percolation are discussed by Lavapuro et al. (2008).

Alley and Leake (2004) suggest that groundwater sustainability should concern the long-term effects of groundwater resource development. In addition to this, values of properties that relate to sustainability of a groundwater system at a given point in time may change with time.

¹ The term sustainable use is older and was used e.g. by Hans Carl von Carlowitz as early as 1713

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4 Groundwater extraction that is considered sustainable today may be considered unsustainable in
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6 the future due to stricter environmental concerns about the discharge rates to GDEs.
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9 10 3.2 Environmental flow and ecosystem water requirements

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12 Quantification of environmental water requirements (EWRs) is a promising method devised to
13 ensure sustained streams of ecosystem goods and services related to water quantity and quality at
14 safe minimum standards for the protection of ecosystem structure and function in both natural
15 and socio-economic systems. Studies about the determination of EWRs for rivers, in particular in
16 terms of fisheries, were initiated in the 1970s. However, recent attempts have been made to take
17 into account other biota, biogeochemical cycles, trophic dynamics and biological productivity
18 and diversity, including in GDEs (e.g. Brown et al., 2008).
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26 Some key issues when determining EWR in a given space and time are listed below:
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29 • Advanced capabilities by remote sensing, geographical information systems and process-
30 based hydrological models should be integrated to fill the knowledge gap about the EWR
31 dynamics of GDEs in response to interactive changes in groundwater attributes, and human-
32 induced disturbances including global climate change.
33
- 34 • Restoration and rehabilitation of damaged GDEs can play a crucial role in sustaining steady
35 state between EWRs by wildlife and socio-economic systems and water supply at safe
36 minimum qualities and quantities of water in a way that all stakeholders are involved in the
37 local process of decision-making.
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- 39 • The precautionary principle requires that actions towards management practices and
40 scientific research and outcomes should be linked by feedback mechanisms that promote
41 adaptive measures in the face of unavoidable uncertainties.
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51 3.4 Economic valuation

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53 The overall objective of public policy is to maximise societal welfare over time from efficient
54 natural resource use, despite externalities that may arise. The key objective of this policy is the
55 allocation of resources in an efficient, sustainable and equitable manner. The impact of this
56 policy should be the establishment of the resulting distribution of costs and benefits to society in
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4 such a way that social ideals are satisfied. Due to the public good aspect of groundwater quality,
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6 its other values are ignored in environmental policing and rational public decision making on
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8 financing preservation or improvement. Therefore, it is essential that the economic benefits of
9
10 groundwater are clearly identified and valued. In other words, as the social opportunity costs and
11
12 external costs of extracting groundwater are not reflected in market prices at all, non-monetary
13
14 approaches to evaluate and suggest how these values and costs (scientific, economic, social and
15
16 cultural) should be integrated in water resource management policies need to be developed.

17
18 A framework widely used for the valuation of natural resources is the total economic value. It
19
20 comprises not only use and non-use values but also indirect use values (Turner et al., 2003).
21
22 Groundwater use values can be direct (commercial and recreational) in that groundwater, when
23
24 abstracted, functions as an input into economic sectors, such as water supply, recreation and
25
26 irrigation (WATECO, 2003). This kind of value could be easy to measure with a market value.
27
28 As groundwater generally supports ecosystems, there can be a number of indirect values as well.
29
30 Groundwater extraction can have an indirect impact on e.g. certain surface waters and soil
31
32 subsidence, (WATECO, 2003). In addition to these use values there is an option value, which
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34 reflects direct or indirect potential future uses of groundwater, e.g. the future value of
35
36 biodiversity. Option values may depend on uncertainty over future resource demand and supply,
37
38 while there is insufficient knowledge on whether and when the good is actually consumed. The
39
40 non-use values of groundwater consist of existence values, derived from the demand to preserve
41
42 groundwater in its natural state without any intention of using it whatsoever. Bequest and
43
44 altruistic value categories capture the value individuals place on leaving groundwater resources
45
46 intact for the use of others. In the case of bequests the use is destined for future generations,
47
48 while altruistic value categories express specific concerns about whether groundwater resources
49
50 are still available to other people living today (Görlach and Interwies, 2003). Two main
51
52 categories of non-market valuation methods are used for eliciting the abovementioned values of
53
54 groundwater: revealed preference and stated preference approaches. Both of these can often be
55
56 time-consuming and costly to use (WATECO, 2003), but are appropriate to provide solutions to
57
58 environmental issues that raise specific problems.

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60 The concept of ecosystem services is used in sustainable resources management. Generally
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62 ecosystem services tend to fall into the categories of open access and pure public services. This
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4 means that they tend to have no producer property rights, ambiguous entitlement structures and
5 prohibitive transaction costs. Aquifers have traditionally represented a classic example of a
6 common pool resource. Collective action by groundwater users could solve the problems that
7 common aquifers face under certain conditions (Schlager, 1995). Lopez-Gunn and Martinez-
8 Cortina (2006) analysed the decisive role of collective actions by groundwater user associations
9 in sustainable groundwater management in a comparative study applied to the three main
10 aquifers in the central Mancha region, Spain. They concluded that while solutions such as
11 subsidies and payments can help mitigate aquifer overuse and temporarily protect GDEs, these
12 are not a long-term option (economically or sustainably) without sound institutional design of
13 water use organisations, favouring self-governance. Valuation of ecosystem services can
14 improve understanding of problems and trade-offs, can be used directly to support decision
15 making, can illustrate the distribution of benefits and thus facilitate cost-sharing for management
16 initiatives and can create market instruments that promote sustainable ecosystem management
17 (Chee, 2004). The concepts of ecosystem services and natural capital can help us recognise the
18 many benefits that nature provides. From an economic point of view, the flows of ecosystem
19 services can be seen as the ‘dividend’ that society receives from natural capital. Maintaining
20 stocks of natural capital allows the sustained provision of future flows of ecosystem services, and
21 thereby helps to ensure enduring human well-being (TEEB, 2010).
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40 4. Ecosystem services

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43 Ecosystem services are the conditions and processes through which natural ecosystems and their
44 constituent species sustain human life. According to the Millennium Ecosystem Assessment
45 (MEA 2005), ecosystem services are the benefits people obtain from ecosystems, and therefore the
46 full range of benefits related to human well-being must be represented in any effective
47 description of ecosystem services. The well-being of every human population in the world is
48 fundamentally and directly dependent on ecosystem services (TEEB, 2008). An ecological
49 understanding of the value of GDEs must be complemented with an awareness of the economic
50 and social impacts of groundwater modification. This can be achieved through a
51 multidisciplinary approach which links environmental, economic and social assessment
52 (Danielopol et al., 2003).
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4 Ordinary resource users may be unable to identify ecosystem functions directly, but rather
5 recognise them through the goods and services they produce and can be assessed in economic,
6 ecological and socio-cultural terms. These include *provisioning services* such as food, water,
7 timber and fibre; *regulating services* that affect climate, floods, disease, wastes and water
8 quality; *cultural services* that provide recreational, aesthetic and spiritual benefits; and
9 *supporting services* such as soil formation, photosynthesis and nutrient cycling (MEA, 2005).
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16 GDEs provide valuable services for human populations. Ecosystems dependent on groundwater
17 at or close to the surface, including rivers and streams, wetlands, flood plains, springs, estuaries,
18 and lagoons, are of particular concern since they are crucial contributors to biodiversity and
19 ecological productivity. They serve for flood control and mitigation; regulate runoff and water
20 supply; improve the quality of surface waters and groundwater; withhold sediments, reduce
21 erosion, stabilise river banks and shorelines and diminish the risk of landslides; improve water
22 infiltration and support water storage in the soil; facilitate groundwater recharge; and improve
23 drainage conditions and natural irrigation. The services or values delivered depend on GDE type
24 (Fig. 1).
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33 The functions and systems dependent on the subsurface presence of groundwater include
34 terrestrial ecosystems, maintenance of global and local air quality, carbon dioxide sequestration,
35 commercially important populations, breeding sites for game stocks, productive soils and arable
36 land, as well as provision of building materials, energy and mineral resources (MEA, 2005;
37 Boulton et al., 2008).
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43 Aquifer and cave ecosystems, including karst, fractured rock and alluvial aquifers, and hyporheic
44 zones of rivers and flood plains play a role in nutrient cycles through the storage, recycling,
45 processing and acquisition of nutrients. For example, subsurface microorganisms recycle
46 nutrients that are important in secondary productivity (Goldscheider et al., 2006). Biological
47 compartments also provide an important ecosystem service in the form of water purification and
48 waste treatment through microbial degradation of organic compounds and potential human
49 pathogens. GDEs also provide cultural services, such as recreational, aesthetic, spiritual and
50 educational benefits.
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4 Groundwater is closely connected to surface water resources. Any pressure on groundwater has a
5 strong impact on the capacity of the dependent ecosystems to provide services. Water discharge
6 from aquifers maintains and sustains river flows, springs and wetlands, especially during dry
7 season and droughts. Thus, overexploitation of groundwater for irrigation or other usage may dry
8 up wetlands, resulting in the collapse of the whole ecosystem, an increase in salinity and a
9 decline in connected activities. Disruption or changes to regulating services (e.g. water
10 regulation, water purification and waste treatment, climate regulation) can have a major impact
11 on groundwater, including a long-term decline in water storage, increased frequency and severity
12 of groundwater droughts, groundwater-related floods, mobilisation of pollutants due to
13 seasonally high watertables and saline intrusion in coastal aquifers due to sea level rise and
14 resource reduction.

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25 The interdependencies between ecosystem services provided by GDEs and groundwater are
26 poorly recognised in decision making and management of water resources. The challenge lies in
27 improving understanding and awareness of the linkages and incorporating these into decision
28 making and management (Fig. 2).
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36 5 Groundwater resources and GDE management in practice 37 38 39

40 Besides local and EU policy, the management of European groundwater resources is dependent
41 on I) past traditions and knowledge, II) hydrogeology, III) climate, IV) land use pressures, V)
42 trends in water supply, and VI) water scarcity. Some cases in Europe (Fig. 3) were reviewed for
43 the GENESIS project (see additional material). Typical threats in Europe include leaching of
44 nitrate and pesticides from agriculture. The increased production of biofuels will aggravate these
45 threats. Leaking sewage pipes, particularly in urban areas, can also introduce nitrates and other
46 contaminants. In several aquifers pollutant concentrations are higher than the limit of 50 mg/L
47 set by the EU Groundwater Directive. Pesticides also pose a major threat and limits have been
48 exceeded in some cases. Cold climates represent a special case, with a low rate of degradation
49 and special conditions for focused recharge from snow melt. In coastal conditions salt water
50 intrusion is a major threat, especially after severe groundwater level decline due to pumping for
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4 irrigation. GDEs were generally not well incorporated in the first RBMPs. Knowledge of
5 pollutant pathways and conceptual models for pollutants are important for correct management
6 actions. However, such models are lacking e.g. for emerging pollutants.
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11 Two GENESIS cases are presented in the following sections to illustrate policy, management
12 and regional aspects in groundwater and GDE management and decision making.
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16 17 5.1 The Mancha Occidental aquifer, Spain

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19 Conflicts between intensive groundwater use and GDE conservation are widespread throughout
20 arid and semiarid regions. In some cases, groundwater depletion by intensive irrigation has led to
21 the degradation of valuable wetland ecosystems and/or the salinisation of soil and groundwater.
22 A remarkable example can be found in the western part of the La Mancha region (Fig. 3), a
23 central plateau in Spain. In this area, farm subsidies (through programmes in the former EU
24 Common Agricultural Policy) encouraged the expansion of irrigation, with positive social and
25 economic effects, but leading to overexploitation of the large aquifer and subsequent degradation
26 of the dependent wetland ecosystems, including the Ramsar-listed National Park ‘Tablas de
27 Daimiel’. Different wetland restoration policies have been implemented over the past two
28 decades (Martinez-Santos et al., 2008). While national policies have focused on a *command-and-*
29 *control* approach (legal bans and obligations on water users, by legal declaration of aquifer
30 overexploitation), regional government and EU policy have focused on compensatory payments
31 to encourage farmers to cut down water use.
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45 In order to mitigate the effects of intensive pumping, the Guadiana Water Authority approved the
46 official declaration of aquifer overexploitation in 1991, including a legal obligation on
47 groundwater user associations, yearly pumping restrictions, and a ban on drilling new wells.
48 Water quotas were controlled mostly by water meters. However pumping restrictions were very
49 difficult to control and enforce (there are currently about 40,000 pumping wells in the area), and
50 illegal pumping became rampant as soon as farmers realised that the Water Authority lacked the
51 resources to enforce its own regulations (Martinez-Santos et al., 2008). Given the limited success
52 of compulsory pumping restrictions and their potential effect on farm income, the Regional
53 Government launched an Agro-Environmental Plan in 1992, mostly funded by the EU, which
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4 granted income compensation payments in return for a reduction in farm water use. The
5 programme had a larger impact than foreseen and was able to achieve its environmental and
6 socio-economic objectives, although it has been criticised for being funding-intensive, as well as
7 for providing a quick fix to the problem rather than instituting lasting changes in the irrigation
8 sector (Fornés et al., 2000). An important effort to include active stakeholder participation within
9 the new context of the EU WFD gave rise to a new Special Plan for the Upper Guadiana basin in
10 2006.
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19 This case study shows that unlike policies relying only on pumping quotas, which are very
20 difficult to enforce, water conservation policies that include a quota system and a compensation
21 scheme can achieve the conservation target, provided that the compensation payment is attractive
22 to farmers and sufficient to compensate their income losses. However, these policies can be
23 costly and are in conflict with the WFD requirement of cost-efficient policies for meeting the
24 good status of all water bodies and the cost recovery of water services. Water pricing policies
25 can also be an effective instrument to induce water conservation strategies. For simulating the
26 impacts and effects of alternative policies, valuation of water productivity and estimation of the
27 water demand functions for different uses are essential. Water pricing policies can also be an
28 effective instrument to induce water conservation strategies. In order to simulate the impacts and
29 effects of alternative policies, valuation of water productivity and estimation of the water
30 demand functions for different uses are essential.
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42 5.2 The Viinivaara and Rokua esker aquifers in Finland

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45 In large parts of the Fenno-Scandian shield, the most common aquifers are glaci-fluvial deposits.
46 Due to these local geological conditions, several thousand groundwater bodies in Finland and
47 Sweden have been delineated as part of the EC Directive work. These sand and gravel ridges
48 form eskers and deltas that are the main source of groundwater. Use of groundwater is increasing
49 and already represents 60-70% of drinking water consumption in Finland. This is due to the
50 higher quality of groundwater and new demands on water safety plans that require several
51 sources of potable water in order to achieve the highest safety standard.
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4 In the Oulu region, the main conflict in groundwater use is related to the Viinivaara and Rokua
5 eskers. Viinivaara is planned to be the main water source for the city of Oulu in the future. The
6 esker discharges into a Natura 2000 peatland (fen) and to several headwater streams relying on
7 groundwater. The main impact of future groundwater use will be on these GDEs, local wells,
8 streams and a valuable ‘kettle’ lake lying above the aquifer. Different scenarios were considered
9 in the environmental impact assessment for water extraction and as a result of this process the
10 planned pumping intensity was moderated to reduce the environmental impact. The permit has
11 finally been approved after several years of processing in the legal system, as the extraction will
12 impact on the Natura 2000 fen. As compensation for decreased low flow, some small-scale
13 reservoirs are planned, but this water is not of the same quality as groundwater. Local residents
14 are strongly against groundwater use as they fear environmental impacts to the adjacent
15 Nuorittajoki river, which is already heavily affected by peat harvesting. Former misuse of the
16 catchment with severe consequences is partly the reason for the public mistrust of the
17 environmental protection and decision making processes.
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31 Another interesting and typical case for the region is the Rokua aquifer, the largest groundwater
32 body in Finland. The entire esker is protected in Natura 2000 and includes a nature reserve. The
33 site has exceptional recreational values, with crystal clear lakes and unique nature. As in most
34 eskers, the system is unconfined and discharges into peatlands that confine the groundwater.
35 These peatlands have been used for agriculture, forestry and peat extraction. Past protection of
36 the site covered only the unconfined sand ridge, so drainage was allowed on the confined part of
37 the esker. Drainage for forestry was supported by government subsidies and was conducted on a
38 large scale in the period 1950-1980. The severe environmental impacts were detected later. For
39 example, impacts on spring ecosystems caused by drainage have been noted (for references see
40 Kløve et al., 2011, this issue). At Rokua, lake declines were observed after a drought in the
41 1980s and also after later drought periods. The key question is whether this decline and variation
42 in lake level is due to drainage or climate variation. As the climate in the past decade has been
43 wet, it seems reasonable to assume that forest drainage is the cause of the reduced water levels.
44 This case illustrates how lack of data can result in huge uncertainty. In Finland, good series of
45 data exist for climate, river flow and snow cover, but downscaling to local conditions is difficult.
46 Land use records are also sparse. Due to several aspects of uncertainty the precautionary
47 principle should be used until more scientific evidence is available.
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6. Conclusions

Groundwater provides valuable services for humans and ecosystems. It is also a major source of potable water and crop irrigation. The use of groundwater has impacts on ecosystems relying on groundwater, a fact that has received little attention thus far. For groundwater impact assessment in the future, significant impacts on ecosystems need to be included. The overall role of groundwater for both aquatic and terrestrial systems also needs to be better understood. This includes the role of groundwater in the hydrological cycle, and in specific ecosystems such as rivers, lakes and wetlands. More exact information is needed on the hydraulic contact mechanism between surface water, terrestrial ecosystems and groundwater. Special attention should be paid to the role of climate variability and change on spatial and temporal distribution of recharge, discharge and temperatures in GDEs. This knowledge is needed to protect and manage the various services that groundwater provides to both ecosystems and society. Currently most monitoring programmes focus on rivers, lakes and groundwater. GDEs should also be included in national monitoring networks and future monitoring should be carried out at the ecosystem scale. An ecological understanding of the value of GDEs must be complemented with an awareness of the economic and social impacts of groundwater modification. This will only be achieved through a multidisciplinary approach which links environmental, economic and social assessment and management.

Despite the development of new legislation, GDEs are at risk from land use and climate change. Groundwater resources have generally not been managed in an integrated way to date, because aquifer systems are difficult to observe. Aquifers are all different and complex, while their responses on impacts are slow as residence times are long. Lack of knowledge is partly also due to lack of long-term monitoring programmes. This is especially true for GDE and groundwater pollution. Efficient pollution management to determine impact and response, e.g. with mathematical modelling, requires time series of data on land use practices and fertiliser use, which are often lacking. Sustainable management is often in conflict with fundamental uses of potable water and food production. The increased production of so-called ‘biofuels’ further aggravates these conflicts. On the other hand, the value of other ecosystem services, such as

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4 recreation and tourism, has become very important. Consequently, the management of
5 groundwater and its dependent ecosystems should better consider the total economic value.
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10 Ecosystem services that GDEs provide for humans, including food production, water purification
11 and recreation, are at serious risk of being lost. Effective management of GDEs and their
12 ecosystem services requires prioritisation of the most valuable ecosystems. In some cases the
13 losses may be irreversible, or at least difficult and costly to reverse. The integration of natural
14 and social sciences can contribute to an increased holistic understanding of relevant processes
15 and problems associated with GDE management and help to design consistent policies. This
16 management approach is based on new technologies for sustainable groundwater exploitation,
17 considering their support capacity and interactions with dependent ecosystems at wider spatial
18 scales (watershed, national and EU scale), as well as involvement of stakeholders in the
19 management and decision making processes. The approach also involves consideration of the
20 socio-economic implications of different policies and a significant effort to educate the main
21 water users and the general public to embrace the overall importance of wetlands and other
22 GDEs.
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35 It is important to note that the use of water resources, including groundwater resources, cannot
36 be developed without affecting the natural environment. Groundwater use should not be defined
37 as either safe or sustainable without carefully analysing and explaining the assumptions about the
38 acceptable long-term effects of groundwater resource development on the environment.
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50 (<http://www.thegenesisproject.eu>) funded by the European Commission 7FP large scale project
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Table 1 Relevant EU policies and their role in GDE management.

Policy	Overall aim	The role of GDEs and how they are included in the policy
Ramsar convention	Protection of habitats	This agreement provided the first framework for protection of wetlands on a voluntary basis.
Birds directive	Protection of birds	Protect breeding and resting areas of which some are GDE.
Habitats directive	Protection of habitats and biodiversity	Protect valuable habitats of which many are GDE such as wetlands and springs. Natura 2000 sites form a EU-wide network of protected areas.
Water Framework Directive	Sustainable use of water resources and to achieve good surface water quality	WFD Guidance document 12 state: I) Protect, enhance and restore wetlands identified as water bodies, where this is necessary to support the achievement of good ecological status or potential. II) Prevent more than very minor anthropogenic disturbance to the hydromorphological condition of surface water bodies at high ecological status including the structure and condition of riparian, lakeshore or inter-tidal zone and hence the condition of any wetlands encompassed by these zones. III) Establish measures to control and mitigate modifications to the structure and condition of riparian zones within wetlands. IV) Wetlands could play a relevant role in facilitating the achievement of other WFD requirements concerning protected areas that do not target wetlands directly.
Directive on Groundwater Protection	Achieve good groundwater status, prevent deterioration (quantitative and chemical), prevent or limit the input of pollutants, implement measures to reverse any significant and sustained upward trend in groundwater bodies.	GDEs have a central role in since the update of the directive in 2006. Groundwater bodies are classified as poor if GDEs are damaged due to pollution from groundwater or less groundwater due to other groundwater uses. The directive requires to control and remedy anthropogenic alterations to groundwater quality and water levels to the extent needed to ensure that such alterations are not causing I) significant damage to terrestrial ecosystems that directly depend on groundwater bodies and II) significant diminution in the chemical or ecological quality of bodies of surface water associated with bodies of groundwater.
Flood Risk Management Directive	Reduce vulnerability to floods	This directive will be implemented in conjunction with the WFD through the coordination of flood risk management plans and RBMPs. Water retention measures are encouraged as an important buffer in the prevention of flooding. This will help to conserve wetlands (and other GDEs).
Climate change (EU white paper)	reduce vulnerability to the impact of climate change	Actions mentioned include: I) to address biodiversity loss and climate change in an integrated matter, and to II) explore the potential for policies and measures to boost ecosystem storage capacity for water. Guidelines should be drafted by 2010 to deal with the impact of climate change on the management of Natura 2000 sites.

List of figures

Fig. 1 Roles and values of GDEs.

Fig. 2 Framework for integrated assessment of GDE services (adapted after de Groot et al., 2002; MEA, 2005).

Fig. 3 Map of GENESIS sites.

Spring	Minor riverbed	Riparian and alluvial forests	Fluvial annexes (Pools, Ponds)	Fens, Swamps	Lakeshores	Roles and Values	
						Flood expansions	Hydromorphologic values
						Low-flow regulation	
						Recharge of aquifers	
						Solid material supply to rivers	
						Nutrient regulations	Ecological / Environmental values
						Toxic retention / Bioremediation	
						Suspended material interception	
						Primary productivity	
						Patrimonial / Cultural richness	Societal values
						Amenities	
						Goods (fishes, etc...)	

	Strong
	Medium
	Low

Fig. 1

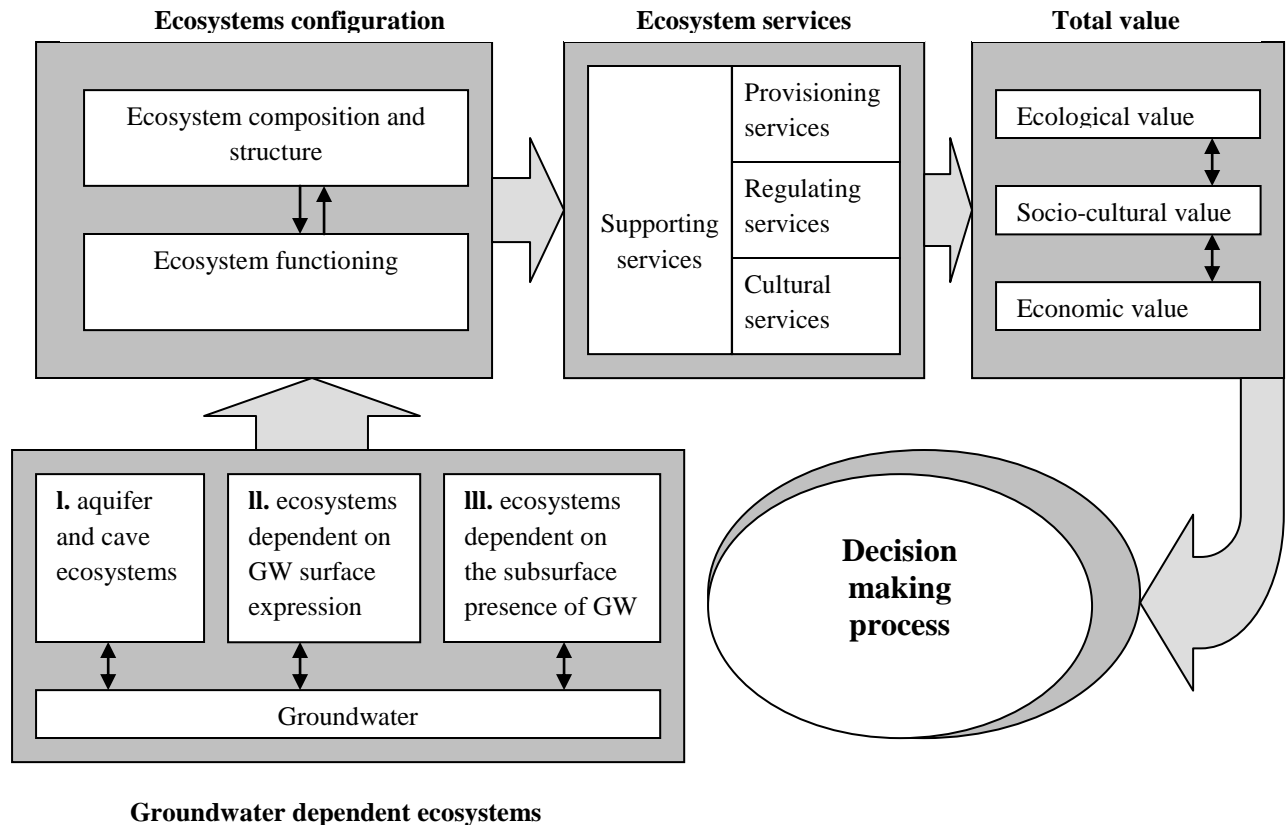


Fig. 2



Fig. 3

Supplementary Material

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