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COMMENT

Incorporating ecological perspectives in European groundwater management policy

Implementation of the European Union (EU) Water Framework Directive (WFD 2000) and its planned supplement 'Directive on the Protection of Groundwater against Pollution' (EU GWD [European Union Groundwater Directive] 2003) demands an initial characterization of all groundwater bodies by national and regional authorities. The main criteria considered in the Directives to define the groundwater (GW) status are quality (chemical) and quantity, but there is the obvious omission of ecological perspective in these. A directive for a comprehensive policy dealing with GW protection at the level of the EU is a prerequisite for human welfare. Additionally, recognition of GW-dependent ecosystems (GDEs) in the EU is equally important for their sustainable management. GW management and policy should recognize the ecological functions of GW and their interactions with GDEs. As they can stretch across national and regional boundaries, political recognition of their importance and the necessity for ecological consistency of management plans have to be emphasized. During the last three decades, a number of researchers have focused their attention on the dynamics and functioning of GW ecosystems and this work could serve as a basis for identifying impacts of changes in key attributes of GDEs. Detailed aspects of GW ecosystems have been comprehensively dealt with (Gibert *et al*. 1994; Wilkens *et al*. 2000; Griebler *et al*. 2001; Danielopol *et al*. 2003). Changes in key attributes of GW ecosystems have had consequences for the environment in the EU and USA (Klijn & Witte 1999; Winter 1999; Sophocleous 2002; Winter *et al*. 2003).

We emphasize here the need for improvements in the proposed EU GWD (2003). For development of an effective water resources management policy, understanding of the interconnections of GW and surface water is fundamental. The intention here is to develop an approach in GW management and policy that integrates hydrology, biogeochemistry, GW ecology and ecohydrology.

Current groundwater policy

Starting in the mid 1970s, the EU enforced the protection of aquatic environments via a number of directives, giving more recognition to human utilitarian aspects (see WFD 2000, Annex VI). Rules to protect GW from pollution in particular have been put in place since adoption of the 'Directive for the protection of groundwater against pollution caused by certain dangerous substances' 1979 (Directive 80/68/EEC). The Directive prohibits direct or indirect discharges of high impact pollutants and should be implemented by 2013. The WFD, which entered into force in 2000 (Directive 2000/60/EC), and the proposed EU GWD (2003) both require the achievement of a 'good groundwater status' with extensive monitoring programme and the protection and restoration of GW bodies. This goal can be achieved only through the coordination of activities in the management of soil, GW and surface water. The criteria for the evaluation of the 'water status', as given in the WFD (2000), are different for surface water and GW. A surface water body achieves 'Good surface water status' when both its ecological and chemical status are good, whereas a GW body achieves 'good groundwater status' when both its quantitative and chemical status are good (WFD 2000, Article 2 [18 & 20]).

The proposed EU GWD is designed to supplement the WFD, focusing on the adoption of specific measures to prevent and control GW pollution, including criteria for (1) assessing the attainment of good chemical status of GW, (2) identifying significant and sustained upward trends, and (3) defining a starting point for trend reversal. However, it completely ignores the ecological status of GW. We argue that there is a particular need to improve this last aspect.

Why there is concern for the ecological status of groundwater

The implementation of the WFD requires integrated water resources management at river basin level and it should address the protection of ecologically valuable areas. The relation between

Table 1 Services and goods provided by groundwater ecosystems (modified from Danielopol *et al*. 2003).

Ecosystem services	*Ecosystem goods*
Self-purification (purification of water through microbiological and physicochemical processes). Attenuation/or elimination of chemical contaminants (natural organic compounds, organic pollutants) where soil functions as a filter and biodegradation medium (has a strong link to long-term resource availability).	High quality, safe drinking water for human consumption and the availability of a reliable water source. Also serves as a stable supply of water for other human needs (agriculture, industry, domestic needs).
Provision of water for the environment as a condition for the function of surface ecosystems (springs, brooks, lakes, wetlands, wet grasslands, estuarine and near-shore marine ecosystems; sets hydrogeochemical conditions for vegetation and associated fauna).	Water for sustainability of GDEs. Habitat for highly adapted organisms that are a unique part of Europe's biodiversity. Organisms indicate ecological conditions in GW and their occurrence depends on historic factors and the hydrological and biogeochemical status of the GW system.

GW recharge and discharge is one of the most important aspects of the protection of ecologically valuable areas. As GDEs are sensitive to such changes, special attention should be given to the effect of land-use changes, to interference from GW extraction and other human activities with the hydrological cycle, and to protection of GW ecosystems. The value of GDEs such as wetlands or terrestrial ecosystems has been long recognized (Hynes 1983), and they show seasonal or episodic reliance on GW to maintain their current composition and functioning.

Recognition of the ecological status of groundwater

GW is not only important in supporting human welfare (Table 1), it is also the basis of life for diverse organisms existing below the earth's surface (Danielopol *et al*. 2003). Subsurface organisms contribute to the services of groundwater purification and long-term storage of good quality water (Herman *et al*. 2001). The complex relationships between the GW and subsurface organisms generate dynamic ecological systems that contribute to ecosystem services and goods (Table 1). The protection of GW should therefore not be restricted to 'good chemical status'. Change in GW composition and availability results in a decline of GDEs, where either specific stream-valley vegetation or other vital aquatic ecosystems are brought under pressure. We refrain here from the need to use ecological criteria similar to those used for the evaluation of surface waters (cf. Technische Commissie Bodenbescherming 2002). In addition, ecotoxicological quality criteria should be considered, which will only be defined when the EU GWD enters into force in 2013.

Consideration of the subsurface heterogeneity

GW ecosystems are heterogeneous environments. There are tremendous differences between GW slowly moving in alluvial sediments and GW rushing through large-solution openings in karstic systems. These contrasts result in different vulnerabilities in relation to point and diffuse sources of pollution. Into our opinion, the proposed EU GWD should account for these differences and elaborate separate protection and management strategies. For instance, different protection schemes are required for GW in karstified rocks compared to porous GW systems. Like the new concepts for surface waters, protection should consider not only distinct GW bodies, but also recharge and discharge areas.

Horizontal link with other strategic EU frameworks and directives

The WFD and the proposed EU GWD should be horizontally linked to other EU environmental strategic frameworks and/or directives. While ecological criteria, such as the biodiversity and ecological integrity, are the subject of the 6th Environmental Action Programme, the Biodiversity Strategy, the Thematic Soil Strategy, and the Birds and Habitats Directive, see Natura 2000 (1992), the proposed EU GWD lacks recognition of these important links and generally neglects ecological criteria.

Establishment of protected groundwater areas
The new EU GWD should achieve EU-wide recognition of areas that are highly vulnerable to water abstraction and pollution, and should help mapping of areas designated for the protection of GW habitats or subsurface species (for example the Dinaric karst systems) and for small river basins as well as GDEs. The latter includes ecosystems reliant on GW influx partially or throughout the year, such as river base-flow systems (for example riparian or seasonal neighbouring streams), wetlands, terrestrial ecosystems, aquifer and cave ecosystems, and GW discharge-dependent cave, estuarine and marine ecosystems. These GW protection areas may coincide with nature protection foci under EU nature protection legislation (Natura 2000, Birds and Habitats Directives) and the favourable condition of Natura 2000 habitats may depend on undisturbed GW systems.

What can ecologists provide to the legislation?

In our opinion, the recently released 'Extended Impact Assessment' (EU EIA 2003), which examines the main features of the proposed EU GWD, is built on requirement of article 17 (Strategies to prevent and control pollution of groundwater) of the WFD (2000), but does not make much use of new ecological knowledge of different subsurface environments in the region (in a landscape with varying geomorphic characteristics from the Mediterranean to the Arctic). The present EU GWD emphasizes the evaluation of the quality of 'chemical status' for aquifers, but nothing is said about the idea that an aquifer has to be viewed as an ecosystem related to the surrounding environment. The fact that the management and/or protection of GW is viewed just within the framework of large river basins (like the Rhine or Danube) offers limited opportunity to address the ecological perspective of GW systems that do not depend directly or do not have direct connections with riverine ecosystems. It is well known that river basins (surface water) and GW basins do not always overlap. Winter *et al.* (2003) have shown that GW flow systems of different magnitudes can be superimposed on one another (as seen in some small watersheds) and, in addition, that GW may change in response to dynamic recharge and discharge conditions (as in low permeability mountain terrains). Other classic examples are karst systems (high permeability), which store and provide a large volume of high-quality drinking water for human communities. In such cases, we have to understand the structure and the dynamics of the ecosystem in order to identify the areas most vulnerable to possible pollution. For instance we should monitor and try to protect the infiltration zone on the karst plateau. Through a multidisciplinary approach involving hydrologists, hydrogeologists, geochemists and ecologists in some countries, like France, we now have useful information on local or regional GW ecosystems, which can be used for a future EU GWD policy (see Gibert *et al.* 1994; Wilkens *et al.* 2000).

While the assessment of the ecological status of surface waters via saprobiological indices is routine (Ghetti 1980; Extence & Ferguson 1989), such evaluation has not been developed for, or adapted to, GW systems. Confronted with a generally lower biodiversity, lower numbers of organisms and rather high percentages of endemic species in subsurface ecosystems, this task will be difficult but not insuperable. The biological analysis of GW microbes may provide information on the presence of pathogens, the dominance of individual functional groups and microbial biodiversity in general. The Dutch experience in developing quality guidelines using microbial toxicity tests (Van Beelen 2003) could be followed. Animal species can be selectively used as indicator organisms for good chemical and ecological water status (Malard *et al.* 1996). The diversity of these organisms should therefore firstly be better mapped for subsequent use in environmental monitoring. A European project, PASCALIS, lead by one of us (Gibert 2001) deals with these aims, and some of this information should be considered for the final version of the EU GWD. Possible approaches for an ecological assessment of GW could include: (1) estimators of species richness and diversity, (2) relationships between taxa and environmental attributes, (3) biodiversity indicators (taxonomic units, functional groups, historical units and conservation units), (4) development of a DNA micro array ('aquifer-chip') that tests for pathogens, functional groups and diversity in the microbial communities, and (5) biomonitoring approaches (bioaccumulation tests and ecotoxicological tests).

Conclusions

We consider the proposed Groundwater Directive incomplete; it lacks ecological background. There is no information on GW ecosystems services and goods and, moreover, complexities of small and large aquifer systems with contrasting geomorphologies have not been taken into consideration. Further, it does not consider basic differences between porous and karstic GW systems and thus lacks separate approaches for their protection. The EU GWD does not contain information on the definition of highly vulnerable GW areas and the protection of diverse GW organisms. In summary, it does not contain clear guidelines for sustainable GW management. The EU GWD should reflect not only the opinions of hydrologists and hydrochemists, but also those of ecologists.

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