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Using a groundwater quality negotiation support system to change land-use management near a drinking-water abstraction in the Netherlands

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Summary A negotiation support system (NSS) was developed to solve groundwater conflicts that arose during land-use management. It was set up in cooperation with the stakeholders involved to provide information on the impact of land use, e.g., agriculture, nature (forested areas), recreation, and urban areas, on the quality of both infiltrating and abstracted groundwater. This NSS combined simulation programs that calculate (1) the concentrations of nitrate in shallow groundwater for each land-use area and (2) the transport of nitrate in the groundwater-saturated zone. The user interface of the NSS enabled scenario analyses. The NSS was validated at a drinking-water abstraction near Holten (the Netherlands) using a spatial planning process aimed at sustainable land-use and groundwater-resource management. Two land-use scenarios were considered: a base scenario reflecting the autonomous development and an adapted land-use scenario. The calculated results for shallow groundwater provided an explicit spatial overview of the impact of historical land use and N application on the quality of abstracted groundwater as well as insight into the impact of changes in land use and N application. Visualization of the conflicting interests of agriculture and the drinking-water abstraction helped all stakeholders accept the necessary changes in land use identified by the adapted land-use scenario of the NSS. These changes were included in the preferred land-use management option in the regional planning process, which has since been formalized. The NSS provided system insight, scoping analyses, and education, in addition to generating quantitative information on the impact of land-use functions on groundwater quality.

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Introduction

Different types of land use, e.g., water abstraction, agriculture, recreation, and urban activities, can have strong, often negative, impacts on the quality and quantity of groundwater and as a result influence each other. For example, nitrate leaching from farmlands can cause nitrate levels to reach harmful concentrations (above the drinking-water limit of 50 mg $NO_3\,L^{-1}$) at nearby drinking-water abstractions (see, e.g., Van Drecht, 1993; Hansen et al., 1991; Steenvoorden et al., 1997). Groundwater abstraction may cause lower crop yields by increasing the depth of the groundwater table, which leads to soil-moisture deficiency. A third example is when groundwater-dependent natural ecosystems become too enriched with nutrients from nearby agricultural fields (e.g., Runhaar et al., 1996).

The impacts of one type of land use on another via groundwater are often characterized by long-term delays and relatively long distances between the cause and the effect. Groundwater heads, for example, may be influenced by abstraction or polders at distances of tens of kilometers and time frames of days to months (e.g., Gehrels et al., 1994). Groundwater quality may be influenced by the quality of recharge in the groundwater system and by groundwater flow characteristics such as the residence times between infiltration and exfiltration points. Even on a small local scale, groundwater residence times may exceed tens of years (e.g., Zaadnoordijk et al., 2004). In addition, groundwater quality may be changed by geohydrochemical reactions in the subsoil, such as denitrification (Tesoriero et al., 2000). These long-distance and long-term effects can hamper the analysis of the impact of current land use on groundwater quantity and quality.

Several studies have been conducted on the relationship between land use and groundwater quality (e.g., Secunda et al., 1998; Thirumalaivasan et al., 2003; Lake et al., 2003). Their emphasis, however, has shifted from describing the vulnerability of the groundwater system to describing the impact of land use since understanding the impact of land use can be used to generate guidelines for sustainable groundwater management (Collin and Melloul, 2001; Kersenbaum et al., 2003). Quality control of groundwater is important because it is a major source of drinking water throughout the world (see, e.g., Foster et al., 1998). Moreover, effective groundwater resource management requires that the socioeconomic context is taken into account (Melloul and Collin, 2001). Burke et al. (1999) argued more generally that social, institutional, and political factors are the primary obstacles to the sustainable management of the world's groundwater resources. Groundwater resource management, therefore, should become part of a common socioeconomic interest and integrated into local spatial planning.

Land use in the Netherlands is intense and, due to the high population density, different types of land use occur within relatively short distances of each other. As a result, groundwater conflicts between the various land uses frequently occur. During the last decades, Dutch environmental policy-making has increasingly moved from the national to the regional and local authorities. At the same time, environmental policy has become embedded in the social and economic processes of parties other than governmental organizations, such as businesses, nongovernmental organizations, and citizens (Driessen and Glasbergen, 2002). As a consequence, many spatial planning processes in the Netherlands are now organized as bottom-up processes in which the stakeholders negotiate with each other in a network structure instead of top-down processes with the government as the dominant party (e.g., De Roo, 1999; Driessen and Glasbergen, 2000; Niekerk, 2000). In such bottom-up processes, it is important that the stakeholders are provided with the knowledge and information they need to actively take part in the process.

One tool that provides such information is a negotiation support system (NSS). Computer-aided NSSs were first used in negotiation processes during the second half of the 1990s (e.g., Hill and Jones, 1996). Thiessen et al. (1998), for example, described the use of an NSS to solve water-resource conflicts. They described the algorithms used for analyzing preferences and for generating alternative feasible agreements. The spectrum of NSSs include (Starke and Rangaswamy, 1999) (1) expert systems that use accumulated knowledge to aid stakeholders preparing for negotiations, (2) a system that combines technologies for individual decision support (DSS) and group decision support (GDSS) and facilitates the actual negotiation process in multiagent settings, and (3) ''autonomous agents'' that are programmed to negotiate on behalf of their human principals. The NSS presented in this paper provides information about the impact of multiple land use (e.g., agriculture, nature, and recreational and urban activities) on the quality of both infiltrating and abstracted groundwater. Moreover, it aids negotiators in overcoming their cognitive limitations and in identifying their (and others') real interests rather than focusing on negotiating positions (see also Fisher and Ury, 1983).

The purpose of the present study was to develop an NSS to solve groundwater conflicts in land-use management. The NSS was designed not to provide a scientific evaluation of the groundwater nitrate issue but to identify the best course of action to resolve the stakeholder-accepted conflict between land use management and groundwater quality. It calculated the impact of land use on groundwater quality in terms of nitrate concentrations because nitrate levels illustrate the conflict between agricultural land use and drinking-water abstraction. Thus, our NSS can be considered to be a groundwater application of a planning support system (PSS), as defined by Geertman and Stillwell (2003). A PSS generates information that can be communicated to and among the stakeholders and used in the planning process. This is different from a decision support system (DSS), which primarily helps decision-makers find the best solution (c.f. Loucks, 1995). The set-up of all three of these support systems requires considerable interaction between the developers and the users.

The applicability of our NSS in changing land-use management was validated in a pilot study of a spatial planning process near the village of Holten in the eastern part of the Netherlands. Conflicts in this region exist between the land uses drinking-water abstraction, agriculture, a natural ecosystem preserve, and recreation. The stakeholders participating in the planning process were the water company, the provincial government, farmers, recreational business-