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REFLECT, a Decision Support System for Harmonizing Spatial Developments with Groundwater Resources

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Abstract A sustainable drinking-water supply requires durable securing of the resource. With an increase in spatial pressure, the need is increasing to prioritize measures based on the vulnerability of the resources and the impact of surrounding land use functions. This is especially challenging in the Province of Overijssel with groundwater abstraction sites in vulnerable Pleistocene sandy soils and increasing spatial pressure from both agricultural and urban areas. The governance of the groundwater abstractions in the Province of Overijssel is based on a combination of precaution and a risk-based approach. The Province has adopted REFLECT to assess the risks of spatial developments. REFLECT is a negotiation support system that gives an overview of the vulnerability of the groundwater abstractions and risks of several land use functions on the groundwater quality. REFLECT has been used to obtain the

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current risk scores of all drinking water abstractions in the Province and following the EU Water Framework Directive. Spatial insight of risks was used to identify and target measures reducing these risks. Moreover, REFLECT has been applied to decide on a local spatial development near an abstraction. Knowledge of the impact of land use changes on groundwater quality helped the municipality harmonizing the spatial plan with the interest of the drinking water abstraction and creating a step-forward in the protection level of the abstraction site. These applications illustrate that REFLECT is an instrument that fits well within risk-based groundwater governance which aims at safeguarding of the public water supply by harmonizing land use functions.

Keywords Groundwater resources · Land use · Decision support system · Governance · Stakeholders · Vulnerability

1 Introduction

A sustainable drinking-water supply requires durable securing of the resource (Moen and Cramer 1987). In the Dutch Province of Overijssel, 100% of the drinking water is produced from groundwater by 24 groundwater abstraction sites ranging from 3 to 12 million m^3/yr. (for locations see Fig. 3). Of these 24 abstraction sites, 20 are located in Pleistocene sandy areas and abstract groundwater from phreatic aquifers. These abstractions are vulnerable for activities at the surface, such as agricultural and urban land use. The Province has delineated groundwater protection areas and recharge areas (capture zones) around the abstractions. The groundwater protection areas are a part of the recharge areas. In these areas the groundwater quality is protected by provincial rules and regulations, serving as regional implementation of the European Water Framework Directive (EU-WFD) (EU 2000). The Province of Overijssel uses a combination of precaution and a risk-based approach in the groundwater protection areas while the groundwater in the recharge area is protected by the risk-based approach only. The groundwater protection areas cover 10% of the provincial land surface and consist for 66% of agriculture, for 25% of natural areas and for 9% for of other land uses, such as urban areas.

Increasing anthropogenic pressures by agriculture, urban and industrial activities can be seen in the groundwater quality since decades (Meinardi 1994). In addition, a recent inventory in Overijssel shows that groundwater quality standards are exceeded in the abstracted groundwater of individual abstraction wells in 12 out of the 24 groundwater abstractions (Province of Overijssel 2013).

Fitting the abstraction sites in a durable way into their surroundings is becoming harder and at the same time more important because of an increase in spatial pressure, a decline in social commitment (Van den Brink and Buitenkamp 2006), the decreasing possibilities to relocate the abstraction sites (Groenhof 2014), the time-bound demands from the EU-WFD (Van den Brink et al. 2014), and the societal demand for the production of safe and reliable drinking water at low costs (LBOW 2007).

The province of Overijssel has decided to improve the use of existing policy instruments rather than creating new provincial rules and regulations. To achieve this, spatial planning rather than prohibitions within groundwater protection areas will be used as instrument because the safeguarding of abstraction sites is optimal when they are surrounded by harmonizing land use functions. This requires a shift in the spatial planning from only permitting certain land use functions to interacting with local stakeholders. Harmonizing land use functions will be invited and combinations of functions based on mutual gains will be stimulated (Agentschap 2012; Van den Brink et al. 2014). This requires insight in the vulnerability within groundwater protection areas and in the risk of different land use functions for the groundwater quality.

The province of Overijssel decided to set up an instrument to provide this insight together with stakeholders, based on the conviction that this would facilitate the interaction with stakeholders when plans for land use changes are being made. Therefor, REFLECT was set up as a negotiation support system (Van den Brink et al. 2008). The requirement to be able to compare different land uses which may have different contaminants and different risks of releasing contamination led to the choice for a qualitative approach. With the choice for expert judgement of the impact of land use functions on groundwater quality, undue preferences by decision makers are avoided (Sadeghfam et al. 2006). This was combined with a relatively simple vulnerability mapping like DRASTIC (Aller et al. 1987), because the impact of a land use on a groundwater abstraction depends on the location inside the capture zone. Based on these considerations, REFLECT has been developed to provide the necessary insight for land use planning in relation to groundwater resources. This paper describes the use of REFLECT 1) in the policy development of the province of Overijssel, and 2) in a local spatial planning process in which a trade-off had to be made between societal responsibilities of various authorities.

2 Method

The Province of Overijssel has integrated the relevant aspects of the three national laws connected to groundwater resource protection into a consistent vision on the provincial environment (Province of Overijssel 2009, 2014). The vision contains the spatial consequences of the public water supply function in the definition of groundwater protection areas and prohibits functions and activities posing a threat on the groundwater quality or provides specific instructions or regulations for other functions and activities, based on precaution. In addition the vision lists harmonizing land use functions. Municipal spatial plans have to comply with the provincial rules and regulations, as is laid down in national environmental legislation. General rules and regulation do not provide specific instructions for local situations. Therefore, the Province can formulate specific instructions and regulations for local land use functions or activities.

Within the recharge areas, precaution cannot be used because no legal ground is available for prohibiting existing functions or activities. However, land use changes are regulated with a risk-based approach. Land use changes within recharge areas have to result in a stand-still regarding the risk for groundwater quality. In groundwater protection areas, the risk-based approach is implemented for the land use functions not prohibited by the precaution part of the vision. Here land use changes have to result in a step-forward with respect to the risk for the groundwater quality. The risk-based approach aims at harmonizing land use functions in the entire recharge area of drinking water abstractions and can be seen as a spatial protection of the abstraction sites. Harmonizing land use functions will be invited and combinations of functions based on mutual gains will be stimulated.

The Province requires the use of REFLECT for assessment of the step-forward and stand-still of the groundwater quality. REFLECT is a knowledge system that visualizes the impact of land use functions and spatial developments on the groundwater quality (Laeven et al. 1999; Van den Brink et al. 2013). It can be used as a negotiation support system (Van den Brink et al. 2008) because it produces a transparent judgment of the land use impacts.

2.1 Set-Up of REFLECT

REFLECT considers a wide range of land use functions from which the impact on groundwater quality is not known exactly and or which cannot be quantified easily e.g. by using a specific marker species. Therefore, REFLECT uses an impact-score for each type of land use. The risk of a land use for the abstraction site is not only a function of this impact score but also of the local vulnerability of the abstraction site. The vulnerability of the abstraction site varies spatially depending on the physical characteristics of the abstraction site, while the impact of the land use functions only depends on the type of land use function.

The vulnerability of the abstraction sites is assessed following Laeven et al. (1999). The stakeholders widely support this approach, in which the vulnerability is based on soil type, thickness of the confining layer if present, and the travel times from the soil surface towards the abstraction wells (Laeven et al. 1999). The vulnerability is expressed in vulnerability-scores of 1–10 (not vulnerable – extremely vulnerable) by combining the maps in a GIS.

REFLECT distinguishes 30 types of land use for the impact score. They are clustered in seven groups: agricultural area, built-up area, inland waterways, nature and natural areas, seas and oceans, recreational areas, semi built-up areas and traffic areas (see Fig. 1). These land use functions correspond to those defined on GIS maps of the Dutch National Bureau of Statistics (CBS 2010) with refinement of agricultural land use functions, based on the Dutch Land use Map (LGN7 2014) also maintained by the national government. The impact-score of each land use function is composed of three sub-scores: 1) Baseline pollution, 2) Calamities, and 3) Governing. The impact-sub-score for baseline pollution quantifies the impact inextricably connected to a land use function, such as the leaching of nutrients and pesticides in agriculture. The impact-sub-score for calamities quantifies the impact of accidents possible for a land use function, such as the collision of trucks with hazardous chemicals. The impact-sub-score for governing is a weighing of the possibility to reduce impacts on the groundwater quality by enforcement of regulations and agreements with specific stakeholders. A variety of activities and a large number of actors usually increase this sub-score.

The overall risk-score is calculated by combining the total impact-score with the vulnerability-score (1:1), which can be expressed as a spatially variable parameter, because the base scores were determined from GIS-maps.

The impact-scores described by Laeven et al. (1999) have recently been actualized (van den Brink et al. 2013) with the Delphi-method (Linstone and Turoff 1975). The Delphi-method is an approach for quantification when explicit quantitative scientific information is lacking while experts do have relevant implicit knowledge. A panel of experts was asked to give the three impact-sub-scores for each of the 30 land use functions. The resulting average sub-scores were returned to the experts for feedback. The variation of the sub-scores was analyzed to decide whether a second round was needed. This was not necessary because the variation of the sub-scores was small compared to the average. The expert panel consisted of 14 experts with a wide range of affiliations: knowledge institutes, universities, water companies,

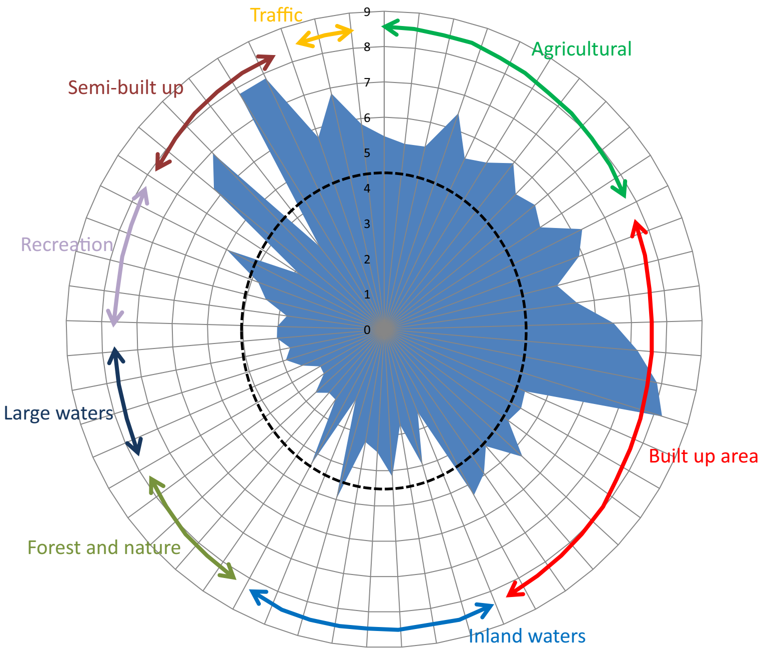

Fig. 1 Land use impact scores in REFLECT

consultants, water boards, provinces and municipalities. The resulting impact-(sub)scores are presented in Fig. 1. The dotted black line in this figure corresponds to the scores of extensive pasture (cattle density of less than 1.5 cows/ha and a restricted use of pesticides). This is a common function in Dutch rural areas and is considered to harmonize with the drinking water function of the groundwater. The impact-sub-score for calamities is low as no serious industrial activities take place and the governing sub-score is low because tens of hectares are the responsibility of only one entrepreneur. Any land use with a higher impact-score is less harmonizing with the drinking water function while land use functions having a lower impact score are considered as harmonious land use functions.

The land use functions such as agriculture, residential areas, industrial areas and major rivers have a higher impact-score compared to extensive agricultural land use. Nature and natural areas, recreational areas, areas for public, social and cultural facilities, cemeteries and inland waters have a low impact-score compared to extensive agricultural land use.

The reliability of the impact-(sub)scores is indicated by the variation in the values of the experts (see Fig. 2).

The baseline sub-scores have smaller variation than the sub-scores for calamity and governing. The calamity sub-score variation is smallest for natural land use functions and surface water. The variation between the experts for the governing sub-scores is smaller for agricultural functions and industrial areas than for other land use functions.

The impact-scores were discussed with the stakeholders in the Province of Overijssel. They consider REFLECT with these impact-scores a useful instrument to quantify the impact of land use and land use change. Using this early in the process of spatial developments prevents conflicts with the provincial authorities in the final stage of the planning process and helps identifying land use functions and land use patterns with harmonize with the abstraction site.

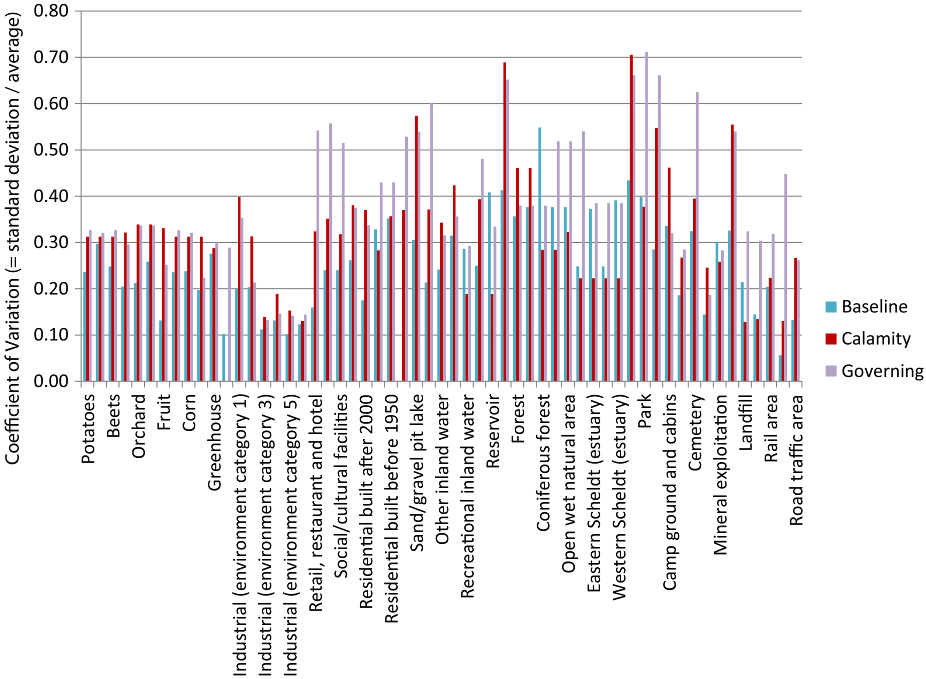

Fig. 2 Coefficient of variation for the impact-sub-scores of the experts in the Delphi-panel

3 Results

The province of Overijssel has used REFLECT to create risk maps of the 24 drinking water abstractions in the Province as a basis for an adequate groundwater protection. The risk score is a combination of the vulnerability score for the abstraction and the impact score for the land use.

The locations of the groundwater abstractions and the vulnerability maps of some selected abstraction sites are presented in Fig. 3.

Figure 3 shows differences in vulnerability both between abstraction sites and within individual recharge areas. These differences are a result of the geohydrology in Overijssel which is controlled by unconsolidated Quaternary sediments, deposited in a subsiding basin. These sediments act as one interconnected aquifer system. The aquifer system is very thick in large parts of the province, but thin at the margins of the basin. Near the Eastern border there is no exploitable aquifers in some areas. In the sandy regions, the upper sub-aquifer generally is unconfined. Locally, brook loam and other less permeable layers form a confining layer (Cramer et al. 2010). As result, the regional geohydrological situation is heterogeneous, resulting in a wide range of travel times of groundwater flowing towards the wells of the abstraction sites.

The vulnerability-scores have been combined with the impact-scores of the current land use to produce maps with the risk-scores within the recharge areas of the abstraction sites (see Fig. 4).

Using the risk maps, areas were identified where land use functions may pose a risk for the quality of the abstraction site. The Province started discussions with the stakeholders

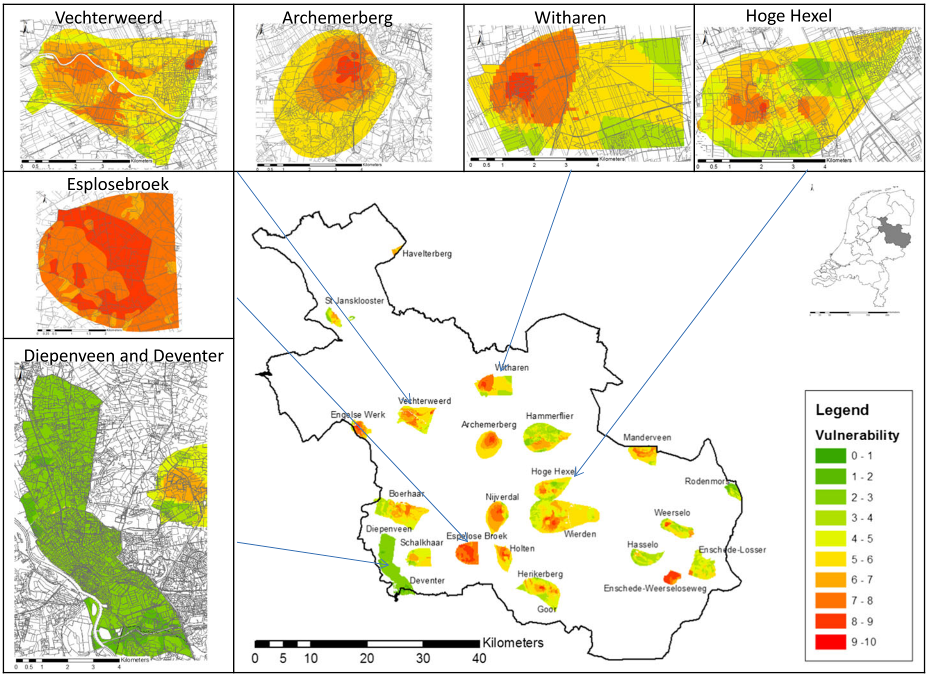

Fig. 3 Abstraction sites in the Province of Overijssel with vulnerability of selected sites

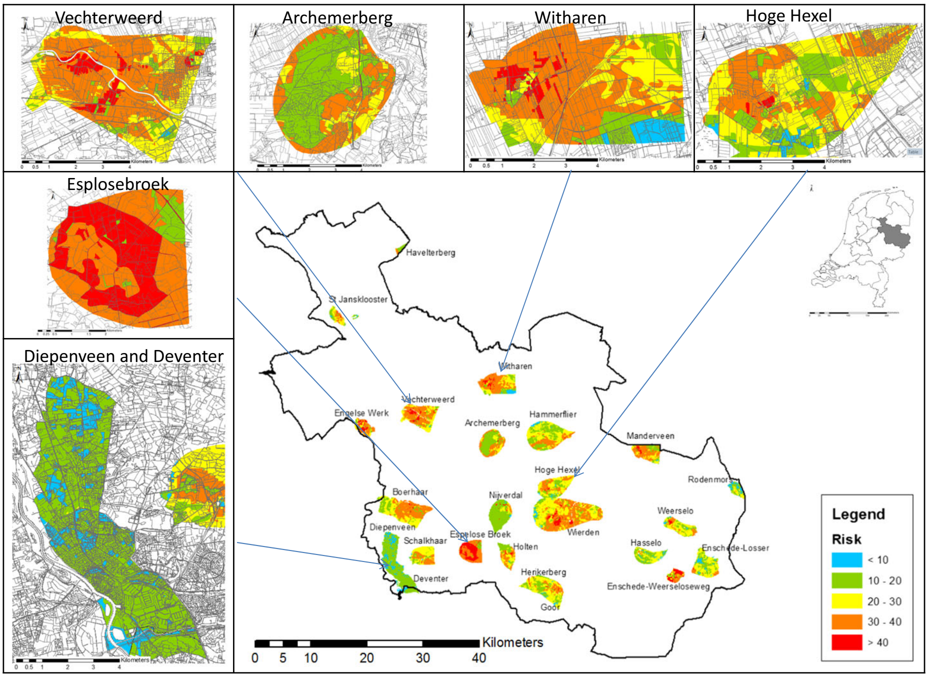

Fig. 4 Risk-scores of the recharge areas of abstraction sites in the Province of Overijssel

connected to the land use functions, to identify and select measures to reduce these risks. As result, an agreement on the implementation of measures was signed in November 2010 (Ten Heggeler et al. 2010). An example is the identification of farms which were invited to take part in a project to improve their nutrient management (cf. Qiu 2009; Giri et al. 2016). The aim was a mutual gain: an increase of the operational result of the farm and a decrease of the nutrient loading of the groundwater (Van den Brink et al. 2013). Evaluation in April 2016 showed that the implementation is on schedule for most measures and that the programme creates awareness of the need to protect the groundwater quality among all stakeholders.

Another recent application of REFLECT is the development of a residential area in the village Hoge Hexel on former agricultural land. The village Hoge Hexel is located in the central part of the Province of Overijssel (see Fig. 3) and lies entirely inside the groundwater protection area. The region enjoys a rural setting with a balance of a small village, farms/dairies, and open public lands. The groundwater abstraction Hoge Hexel is vulnerable due to the absence of covering layers (see Fig. 3). As result, the travel times are short: 20% of the abstracted volume has travel times of less than 20 years, 50% of less than 50 years, and 80% of less than 100 years. The land use in the recharge area is 73% agriculture, 16% urban and 11% nature. Groundwater quality issues are related to high historical and actual use of nutrients, resulting in hardness and high concentrations of sulphate and nickel because of denitrification by pyrite in the sediment (Province of Overijssel 2013).

The spatial development comprises a residential area of 24 houses within the groundwater protection area of the abstraction site Hoge Hexel (see Fig. 3). This land use change is not prohibited following the precautionary protection. Thus, the land use change is only permitted within a groundwater protection area when a risk assessment shows that the development will result in a step-forward regarding the risk of groundwater quality.

The municipality consulted the province in an early stage of the process to investigate the feasibility of the spatial plan. The dialogue between the municipality and the province was about balancing the societal responsibilities of the municipality and province to be able to reach agreement on the way the requirements for the land use change would be met. The municipality and the province agreed to the use of REFLECT to assess the risks and to determine whether the spatial development would be a step-forward for the groundwater quality.

The results of the REFLECT analysis are shown in Fig. 5. These results show that this land use change will result in a decrease of the impact-scores and consequently also in a decrease of

Fig. 5 REFLECT-analysis of the risks for the extension of the village of Hoge Hexel

the risk-scores. The vulnerability scores do not change since they only depend on the abstraction and geohydrological setting, which are not influenced by the land use. The decrease of the impact of the land use change is guaranteed by additional measures which were integrated in the design of the village extension, such as collecting and purifying storm water and discharging it to surface water outside the groundwater protection area.

4 Discussion

These case studies illustrates that the provincial policy framework is adequate in safeguarding the drinking water abstractions while on the other hand it is open for negotiations regarding other societal needs. REFLECT facilitates this process by providing an informed basis of dialogue as a key towards an effective protection of groundwater resources.

Compared to existing approaches REFLECT is different in several aspects. Previous researchers often focussed on a single type of contamination, mainly agricultural non-point sources of pollution: Secunda et al. (1998) focus on nitrates. Thapinta and Hudak (2003) consider pesticides. Giri et al. (2016) focus on nutrients. REFLECT considers all types of contaminations from all types of land uses. Combining impact of land use with the vulnerability of aquifers is not new. Starting from the 1980-ties vulnerability mapping of aquifers was done. This resulted in instruments like DRASTIC (Aller et al. 1987). Secunda et al. (1998) and Al Adamat et al. (2003) added existing pollution from current land use to DRASTIC. REFLECT does not only account for the actual impact of land uses but also for possible calamities and governing issues related to the various land uses. The governance and enforcement of legislation is an important issue for groundwater quality, which is not always accounted for in practice (Lerner and Harris 2009). In addition, REFLECT has been developed in close cooperation with stakeholders involved in spatial planning to obtain acceptance and support from all stakeholders and increase insight and awareness of the impact of land use and land use change on groundwater quality.

A consequence of the cooperative set up of REFLECT and the use of commonly available GIS-maps, is its simplicity. To be able for the expert panel to distinguish between land use functions, only 30 main land uses were used excluding detailed characteristics. In addition, the scores are qualitatively which hampers the possibility of calibrating the results with groundwater quality measurements. Depending on the size and consequences of the land use change, additional and more detailed studies – such as an environmental impact assessment with deterministic modelling of specific contaminants – may be appropriate.

REFLECT only considering threats from surficial land use, not from underground activities such as deep mining, waste water injection, ATES, fracking, subsurface storage of radio-active waste. These threats may be negligible for most spatial plans, but can be relevant (e.g. Qiang et al. 2016).

The collaborative way in which REFLECT is applied contributes to a common understanding of the groundwater quality issues and acceptance by the stakeholders (Tidwell and Van den Brink 2008). As a result, the stakeholders accept that measures may be necessary because of the risks of land use functions for an abstraction site.

5 Conclusion

REFLECT is an instrument that fits well within risk-based groundwater governance which aims at safeguarding of the public water supply by harmonizing land use functions. REFLECT contributes to joint fact finding and common understanding regarding complex issues - like vulnerability-, impact- and risk-scores – as basis of well-informed negotiations about measures and spatial development plans between all stakeholders.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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