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The groundwater contribution to surface water contamination in a region with intensive agricultural land use (Noord-Brabant, The Netherlands)

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Water quality monitoring data show the importance of the groundwater contribution to surface water pollution.

Abstract

Traditionally, monitoring of soil, groundwater and surface water quality is coordinated by different authorities in the Netherlands. Nowadays, the European Water Framework Directive (EU, 2000) stimulates an integrated approach of the complete soil-groundwater-surface water system. Based on water quality data from several test catchments, we propose a conceptual model stating that stream water quality at different discharges is the result of different mixing ratios of groundwater from different depths. This concept is used for a regional study of the groundwater contribution to surface water contamination in the Dutch province of Noord-Brabant, using the large amount of available data from the regional monitoring networks. The results show that groundwater is a dominant source of surface water contamination. The poor chemical condition of upper and shallow groundwater leads to exceedance of the quality standards in receiving surface waters, especially during quick flow periods.

Keywords: Groundwater quality; Surface water quality; Base flow; Quick flow; Monitoring

1. Introduction

Pollution of groundwater and surface water by diffuse sources is a serious problem in the EU and especially in the Netherlands, due to intensive livestock farming (Campling et al., 2005). Use of fertilizer and animal manure in agricultural areas is the most important non-point source in most Dutch rural catchments. Leaching of nutrients and heavy metals cause groundwater concentrations to exceed local quality targets, especially in the sandy regions (Reijnders et al., 1998; Fraters et al., 1998; Broers, 2002; Broers and Van der Grift, 2004). Discharge of groundwater from agricultural land towards the surface water system may cause exceedance of surface water quality standards as well (Van der Molen et al., 1998; Oenema and Roest, 1998; Oenema et al., 2005).

Ground- and surface water management and monitoring in the Netherlands is coordinated by different authorities operating in different geographical sub-regions, while national and European governments are stimulating a more integrated approach to managing the soil-groundwater-surface water system. The European Water Framework Directive (EU, 2000) for example states that pollution of groundwater bodies must not cause dependent surface water bodies to fail to meet their good status objectives.

In the agricultural province of Noord-Brabant in the Netherlands large amounts of water quality data are available. Groundwater and surface water quality data from the regional monitoring programs are compared to different threshold values and reported in separate publications (e.g. Van der Grift et al., 2004; Waterschap De Dommel, 2004). These

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publications indicate that both shallow groundwater and surface waters in Noord-Brabant often do not meet their quality standards. Comparing water quality studies reveals that the same problematic solutes appear in both groundwater and surface water. The most problematic inorganic agrochemicals are nutrients (NO_3-N, P-tot, SO_4) and heavy metals (Zn, Cu, Ni). To date, no effort has been made to comparison and integration of the surface and groundwater quality data from the regional monitoring networks.

Different modeling studies indicate that agriculture is an important source of nutrients and heavy metals (Oenema et al., 2005; Schoumans et al., 2002; Bonten and Brus, 2006). These models indicate that nutrient and heavy metal concentrations in groundwater discharged from agricultural land exceed the relevant quality standards for surface water in Noord-Brabant. Comparing the estimated groundwater contribution with estimated inputs from other sources produces a rough estimate of the relative contribution of groundwater to surface water quality. A recent study estimates that groundwater contributes approximately 47% of total-N loads to surface waters in Noord-Brabant, 47% of total-P, 69% of Zn, 16% of Cu and 74% of Ni (Van Vliet et al., 2006).

Direct relations between land use, groundwater quality and surface water quality were observed in several field and catchment scale studies (e.g. Hyer et al., 2001; Jarvie et al., 2001; Ahearn et al., 2004; Gelbrecht et al., 2005). Measurements showed changes in surface water quality during storm events. Hyer et al. (2001) for example observed decreasing concentrations of silica and calcium during storm events in an agricultural catchment. Concentrations of nitrate, DOC, potassium, chloride and sulphate increased during storm events. These results indicate that surface water quality during base flow conditions is mainly controlled by deeper groundwater chemistry (high concentrations of silica and calcium). The influence of upper groundwater, soil water and overland flow increases during peak flow conditions. In an agricultural catchment, this leads to higher concentrations of agricultural pollutants.

In spite of estimates from modeling studies identifying groundwater as an important source for surface water contamination and the direct relations between groundwater and surface water reported in the literature, extensive sets of groundwater and surface water quality data such as available in Noord-Brabant, have never been compared. Consequently, no direct support exists for the assumed importance of groundwater composition for surface water quality on a regional scale. If the groundwater contribution can be shown to be a dominant factor, surface water quality management, which is traditionally focused on the surface water system itself, should aim at groundwater quality improvement as well.

The objective of the present study was to estimate the groundwater contribution to surface water contamination using monitoring data from the regional monitoring programs in Noord-Brabant. The study focused on problematic solutes in Dutch surface waters: nutrients (NO_3-N, P-tot, SO_4) and heavy metals (Zn, Cu, Ni).

Groundwater quality data from the regional monitoring program were used to characterize groundwater quality at different depth levels. Data from surface water monitoring programs were used to characterize surface water quality during base flow, intermediate flow and quick flow conditions. This approach allowed us to compare groundwater quality at different depths with surface water quality during different flow conditions.

2. Description of the study area and the extensive sets of groundwater and surface water quality data

2.1. Study area

Fig. 1a shows the location of Noord-Brabant within the Netherlands. The total area of Noord-Brabant is 5100 km^2, of which 62% is in agricultural use. Noord-Brabant is one of the areas in Europe which is most affected by agricultural pollution, because of intensive livestock farming which produces a large surplus of manure (Campling et al., 2005; Broers and Van der Grift, 2004; Meinardi et al., 2005; Vermooten et al., 2006; Visser et al., 2007).

Noord-Brabant is a relatively flat area and groundwater tables are generally shallow, usually within 1–3 m below the surface. The subsurface consists of fluvial Pleistocene unconsolidated sand and gravel deposits from the Meuse river system, overlain by a 2–35 m thick cover of fluvio-periglacial and eolian deposits consisting of fine sands and loam. The area is drained by a series of brooks (Fig. 1b). The original drainage network was artificially extended during the 20th century, to allow for agricultural use of the poorly drained areas. This resulted in a dense network of ditches, drains and small watercourses.

2.2. Groundwater quality monitoring in the study area

Groundwater quality monitoring in Noord-Brabant is coordinated by the provincial government. Locations were selected using a concept of stratified random sampling from homogeneous areas with similar land use, soil types and geohydrological positioning (Broers, 2002). Eleven homogeneous areas were distinguished, each of them representing a specific combination of vulnerability and pollution loading. For example, the homogeneous area ‘agricultural land-sand-recharge’ was considered vulnerable for leaching of agricultural pollutants to groundwater. The amount of groundwater sampling wells per homogeneous area was determined according to the total extend of the homogeneous area and the a priori presumed risk for groundwater contamination. Therefore, relatively more wells were installed in the homogenous area ‘agricultural land-sand-recharge’ compared to, for example, the homogeneous area ‘nature-discharge’.

Groundwater quality is measured at different depths below the surface. The upper meter of groundwater is sampled in temporary hand-drilled holes. In this paper, this groundwater is referred to as ‘upper groundwater’. The deeper groundwater is sampled using specially designed multi-level observations wells with 2 m long screens at typical depths of about 10 and 25 m below the surface (Van Duijvenbooden et al, 1985;