Chapter 1

1 General introduction
CHAPTER 1

1.1 Background

Groundwater is of major societal significance for many well-known reasons. One of the most important ones is that groundwater normally offers a direct and hygienically safe source of drinking water for public and individual supply. Groundwater resources, however, are becoming extremely vulnerable to human interference because of their hydrogeological structure, the increasing demographical pressure and the multitude and variety of anthropogenic hazards. For this reason, demanding legislation has been implemented (EU, 2000; 2006b; 2008; USEPA, 1974; 1996), in order to guarantee the protection of such valuable resources, by enforcing governments to monitor and assess the quality and quantity of their waters on the basis of common criteria and to identify and reverse groundwater pollution trends.

Numerous national groundwater quality monitoring networks (NGQMNs) are being developed for this purpose, not only in the US (Rosen and Lapham, 2008) and Europe like in Denmark (Juhler and Felding, 2003), The Netherlands (van Duijvenbooden et al., 1993) and the UK (Ward et al., 2004), but also in other countries, a.o. Egypt (Dawoud, 2004), Korea (Kim et al., 1995; Lee et al., 2007), New Zealand (Daughney and Reeves, 2005) and South Africa (Parsons and Tredoux, 1995). Such networks are regularly monitored to fulfill three main purposes: (1) establish the actual groundwater quality in relation to soil use, soil type and hydrogeological conditions (Boumans et al., 2005; Frapporti et al., 1993; Fraters et al., 1998; Meinardi, 2003; Pebesma and de Kwaadsteniet, 1997; Reijnders et al., 1998; van den Brink et al., 2007); (2) identify trends in groundwater quality (Batlle Aguilar et al., 2007; Boumans et al., 2005; Broers and van der Grift, 2004; Burrow et al., 2007; 2008; Daughney and Reeves, 2006; Frapporti et al., 1994; Reynolds-Vargas et al., 2006; Stuart et al., 2007; Visser et al., 2009; Xu et al., 2007); and (3) establish the regional natural background level of concentrations in groundwater (Coetsiers et al., 2009; Edmunds et al., 2002; Edmunds and Shand, 2008; Fraters et al., 2001; Lee and Helsel, 2005; Limbrick, 2003; Wendland et al., 2008).

The actual groundwater quality is successfully established with data gathered via these networks. However, groundwater quality trend detection and quantification of natural background levels (NBLs) are hindered by insufficient length of time series, which in most cases do not cover the period of interest (Visser, 2009). Such networks are operational for 20 to 30 years at most, while the main groundwater quality deteriorating processes, due to intensive agriculture, urbanization, industrial activities and atmospheric pollution, threaten groundwater resources for more than 60 years.

A monitoring network that is available in most countries and constitutes an attractive (inter)national monitoring system for evaluating the chemical state of groundwater and fulfill the above mentioned three purposes is the network of public supply well fields (PSWFs). A PSWF is a coherent set of pumping wells delivering groundwater to be distributed to the public as drinking water, either without or after treatment. PSWFs are monitored on a regular basis as an integral part of the quality surveillance of national drinking water supply, in compliance with the relevant national drinking water act (EU, 2000; 2006b; 2008; USEPA, 1974; 1996). In The Netherlands, where the period of record begins in 1898, such network provides valuable information on the quality status of groundwater around year 1900 and its evolution through more than a century. The earliest data provide a valuable means to establish the natural background composition of groundwater resources used for drinking preparation purposes. Advantages of the PSWF network may consist of long data records, extensive analytical programs, and representativity for the relatively large volumes of water pumped, which are registered as well. The main disadvantage, however, is the more elaborate interpretation of such data, due to misleading effects resulting from variable pumping schemes during sampling and/or well field adaptation measures, which mask the effects of environmental problems by dilution, reallocation or changing the water sources. Guidelines to avoid these problems are introduced in (Mendizabal and Stuyfzand, 2009, Chapter 2).

1.2 Aim and research questions

The aim of this thesis is, in line with the above arguments, to determine the hydrochemical status and quality developments of the groundwater used in The Netherlands for drinking water production purposes, as based on 110 years of PSWF monitoring. For this purpose, first the hydrochemical status of individual PSWFs is diagnosed and results are then upgraded to the
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The main body of this thesis consists of seven chapters. Chapters 2 to 6 correspond to papers that have either been published in or submitted to a peer-reviewed journal. Chapters 2, 3 and 5 address respectively objectives 1, 2 and 5. Objectives 3 and 4 are addressed in chapter 4 and objectives 6 and 7 in chapter 6. The synthesis in chapter 7 summarizes and integrates the main results of the thesis.

In Chapter 2, hydrochemical data records from public supply well fields are shown to be a valuable national monitoring network for evaluating the quality status of groundwater. This network has been regularly monitored for more than 100 years, but it does present the complications of interpreting mixed samples of waters with different age, origin and recharge conditions, and also of changes in abstraction regime. Guidelines for the proper interpretation of such data are presented, supported by some examples of application.

In Chapter 3, new software is presented for the efficient management, control, analysis and presentation of water quality data in four dimensions (X, Y, Z, t). HyCA (Hydrochemical Analysis) is a computer program primarily developed within this thesis, in order to facilitate the analysis and interpretation of large databases, such as the Dutch network of PSWFs. The results of this thesis would have never been the same without such a tool.

In Chapter 4 a new international PSWF typology is presented, by addressing the spatial distribution of groundwater bodies with specific origins (hydrosomes) and characteristic hydrochemical zones (facies) within each hydrosome. The origin is determined by environmental tracers or geomorphological and potentiometric maps, the facies by combining age, redox and alkalinity indices. This typology forms the basis for the analyses performed in Chapter 5 and Chapter 6 and to upgrade results obtained for individual PSWFs to the GWB level on a national scale.

The results obtained in Chapter 4 are further developed in Chapter 5 into VIP, a single Intrinsic Vulnerability Index towards anthropogenic Pollution, and VIP_X, a Specific Vulnerability Index towards Pollutant X, with X being either a main constituent, trace element or organic compound. VIP combines the age, redox and alkalinity indices introduced in Chapter 4 with the surface water fraction of the pumped water. VIP_X takes also into account specific characteristics of parameter X and the land use and pollution risk of X within the groundwater catchment area.

In Chapter 6, NBLs are calculated for selected parameters, by applying statistical trend detection methods to historical water quality data series from PSWFs, both at the PSWF and GWB level. Trends are normalized to drinking water standards and aggregated into specific trend bundles to identify the responsible hydrochemical processes.

The synthesis in chapter 7 summarizes the main conclusions from the foregoing chapters to provide an overview of the methods developed to establish the actual hydrochemical status and quality developments of groundwater as used for drinking water production in The Netherlands.