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Long-term geochemical and hydraulic measurements in a characteristic confined/unconfined aquifer system of the younger Pleistocene in northeast Germany

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Abstract

The paper presents a data base of hydrochemical and hydraulic groundwater measurements of a younger Pleistocene multilayered, unconfined/confined aquifer system in NE Germany. The Institute of Landscape Hydrology of the Leibniz Centre for Agricultural Landscape Research (ZALF) e. V. operates seven groundwater monitoring wells in the Quillow catchment located in the Uckermark region (Federal State of Brandenburg, Germany). From July 2000 to March 2014, water samples were collected periodically on different days of the year and at depths between 3 and 5 m (shallow wells) and 20 and 25 m (deeper wells) below the surface. The parameters pH value, redox potential, electric conductivity, water temperature, oxygen content, spectral absorption coefficient and concentration of hydrogen carbonate, ammonium, phosphate, chloride, bromite, nitrite, sulfate, sodium, potassium, magnesium, calcite, dissolved organic carbon, iron(II) and manganese were determined for each sample (doi:10.4228/ZALF.2000.266). The measurements, taken over a period of 14 years, include a high variation of hydraulic situations represented by a corresponding database of detected groundwater heads. The hydraulic head was measured between 2000 and 2014 (doi:10.4228/ZALF.2000.272).

1 Introduction

Groundwater quality is mainly influenced by intense reactions and processes controlled by local geological/stratigraphic conditions and the corresponding regional hydraulic situation (Hannappel and Voigt, 1997). The grade of aquifer coverage, for example, shows a high degree of correlation with the environmental redox conditions in groundwater systems (Merz et al., 2009). In highly structured Pleistocene systems, anthropogenic impacts such as water withdrawal for drinking water production, nutrient leaching due to intensive agricultural land use or decreasing groundwater levels caused by climate change often lead to complex effects, the identification and quantitative assessment of which remains a challenging task (Milly et al., 2005; Germer et al., 2011; Cubasch

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and Kadow, 2011). Changing hydraulic boundary conditions and how they influence the observed dynamics of the subsurface water geochemistry are poorly understood (Hansen et al., 2011). The cause-effect chains of different impacts often remain unclear. A variety of issues such as surface water–groundwater interaction, non-steady natural conditions and a decrease in groundwater recharge have to be considered (Ficklin et al., 2013; Rassam et al., 2013). For this reason, this data base, including complex geochemical and hydraulic interactions, can be used for further investigation regarding a 14 year period of groundwater measurements under the impact of global change.

The data bases include original data for 177 groundwater analyses with 20 measured and two calculated geochemical parameters each and more than 19 000 data of groundwater heads. The data were collected from a typical younger Pleistocene catchment (River Quillow), located some 65 km northeast of Berlin (Fig. 1). Two aquifers were sampled along a transect: a local shallow, unconfined aquifer that seasonally falls dry (gauge identifiers 199, 200 and 202) and a deeper, confined aquifer (gauge identifiers 198, 201 and 203). The two aquifers are separated by a 5 to 15 m thick till layer of Weichselian age (Fig. 2). No direct hydraulic contact was confirmed between the aquifers. The hydrogeological structure of a local upper, unconfined aquifer underlain by regional confined aquifer systems is typical for the complex younger Pleistocene landscape. Hydraulically, these regions are characterized by regional transit and local recharge dynamics. A single monitoring well (gauge identifier 204) is located in the water catchment of the river Quillow (Fig. 1). In the immediate vicinity of the river, the upper aquifer and the till layer crop out and the deeper groundwater discharges into the Quillow River under unconfined conditions.

In the period from 2000 to 2014, hydrochemical parameters were measured in the hydrochemical laboratory of ZALF e. V. Müncheberg. The samples were collected from seven groundwater observation wells in the Quillow catchment of the Uckermark region (Federal State of Brandenburg, Germany). The data base includes the geochemical properties and hydraulic groundwater head variations of local unconfined

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and regional confined aquifer systems in a typical younger Pleistocene water catchment of the glacial landscape in northeast Europe. The data base also includes information about the geotagged location, the sample depth, filter depth and well head position in m a.s.l.. All parameters are available via doi:10.4228/ZALF.2000.266 and doi:10.4228/ZALF.2000.272. Information about the methodology applied and the measurement techniques is provided below.

2 Materials and methods

2.1 Study area

The study area, a typical younger Pleistocene catchment of the River Quillow, is located some 65 km northeast of Berlin, Germany (Fig. 1). An area of approximately 135 km^2 is assigned as subsurface catchment in the official hydrogeological map of Brandenburg (State Office for Mining, 2012), which integrates data from the major Pleistocene aquifers. The topography of this till-dominated region is characterized by gently rolling hills, which gives the area its name – "Hummocky Landscape" (Gerke et al., 2010). Altitude decreases from 80 m a.s.l. in the western part of the catchment to 30 m a.s.l. in the southeast (Glacial Valley of the Ucker). Correspondingly, regional groundwater flow is directed to the east/southeast; the River Quillow is the main drainage recipient of the region. The unconsolidated sediments form a series of layered Pleistocene and Tertiary aquifers of about 80 to 140 m thickness with a 50 m thick Oligocene marine Rupel–Clay layer as a lower confining bed. The complete series consists of permeable marine and limnic sediments of the Upper Oligocene and Miocene (thickness 5–15 m) and a complex interplay between glacial deposits of the Pleistocene with a vertical extent up to > 100 m. These deposits, dominated by sediments from the Elster, Saalian and Weichselian glaciations, can be divided into different aquifers separated by till layers. However, the thickness of the sediments varies considerably, including several subglacial trenches.

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The hydrogeological structure in the Uckermark region is very complex. Hydrologically, this region belongs to a transit unit of the Pleistocene landscape. In glacially formed Pleistocene landscapes, transit regions are characterized by regional aquifers, which are largely covered by thick layers of till. These aquifers of Saalian age are characterized by relatively low hydraulic gradients, low flow velocities, and confined hydraulic conditions. Local groundwater recharge plays only a minor role in the regional water budget. Local, unconfined and only temporarily saturated aquifers of Weichselian age are deposited above the till layers. Due to the short distance to the groundwater table and the missing till layer, local aquifers are vulnerable to nutrient input by agricultural land use (Böhlke et al., 2002). The geochemical environment of this groundwater is characterized by high oxygen contents with low DOC concentrations ($< 3\,\mathrm{mg\,L^{-1}}$). The oxygen content reaches nearly saturation level. The redox potential of $> 250\,\mathrm{mV}$ and trace element concentrations below the detection limits are distinct indicators of stable aerobe conditions. Budget calculations by Wurbs et al. (2000) revealed that the nitrate concentration in sandy, aerobe and uncovered pleistocene aquifers was controlled exclusively by the quantity of N-surplus from the agricultural management system. The in situ denitrification process plays no quantitative role (Kersebaum, 2000). Hydraulically, these local shallow aquifers are connected relatively quickly to the smaller surface water system and, therefore, if they are hydrous, they are mainly responsible for the relatively high nutrient load of the surface water system (Behrendt and Dannowski, 2005; Bachor et al., 2012). The underlying deeper aquifer systems in this region are well protected from diffuse nitrate and oxygen inputs by the till cover. Due to a lack of oxygen, a stable anaerobic environment can be observed. The nutrient concentrations in the groundwater are low. These aquifers are connected to the surface water system via base flow; nutrient input quantities by deep groundwater plays only a minor role (Merz et al., 2009).

Land use in the catchment is mixed agriculture and forest, dominated by pines in the highlands and agriculture and grassland in the lowland areas. Annual precipitation data collected at Dedelow meteorological station (approximately 20 km east) ranges

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between 490 and 640 mm per year, indicating a temperate to continental climate. Mean annual groundwater recharge is relatively low, at approximately 70 to 90 mm a^{-1}, corresponding to 1.5 $L s^{-1} km^{-2}$ subsurface discharge (Lahmer, 2003). The regional discharge of the River Quillow ranges between 0.8 and 6.8 $m^3 s^{-1}$, which corresponds to 0.8 to 17 $L s^{-1} km^{-2}$.

2.2 Drilling methods

The groundwater monitoring wells were installed between summer 1999 and spring 2000. A drilling unit by the company NORDMEYER RSB 0/1.4 with top drive and hydraulic hammer was used to install the wells. The equipment enables 2″ groundwater monitoring wells to be installed using a hollow drilling auger system and driving core soundings down to a depth of 30 m. The piezometers are made of high-density polyethylene (PE-HD) with a 1 m filter screen (0.2 mm) at the deepest position of the well.

2.3 Groundwater sampling and analytical methods

Groundwater sampling was carried out in the field using a DANFOSS HP1 submerged pump with a pumping rate of 3–4 $L min^{-1}$. Measurements of the pH value, redox potential, dissolved O_2, conductivity and temperature were carried out in situ using a flow cell. Samples were retrieved in accordance with official DVWK guidelines (DVWK, 1992). The samples were filtered using 0.22 µm membrane filters to exclude suspended particles, precipitations of Fe and Mn (hydr)oxides and colloids. Samples for cation analysis were preserved with concentrated HNO_3. Alkalinity samples were collected in gasproof glass bottles and analyzed immediately in the laboratory. Full water analysis was generally performed one day after sampling, after the samples had been stored overnight at 4 °C.

Water samples were analyzed for Ca, Mg, K, Na, Cl, NO_3, NO_2 and SO_4 by ion chromatography (METROHM IC882) using the column Metrosep C 4–250/4.0 for the cations and column Metrosep A Supp 4–250/4 for the anions. Iron and manganese was determined by ICP-AES (JOBIN YVON). Alkalinity was determined by titration using SCHOTT Titrolein 96. NH_4 and PO_4 were measured photometrically using a SPECORD 200, ANALYTIK JENA. Dissolved organic carbon (DOC) was determined as carbon dioxide using a SHIMATZU-TOC Analyzer following catalytic oxidation. Table 1 provides a detailed overview of the data base content.

2.4 Hydraulic data

The groundwater heads were measured using an automatic data logger system and manually by a light plummet. The wells with the deep filter screen connected to the second, confined aquifer system (gauge identifiers 198, 201, 203 and 204) were equipped with an automatic data logger system from Ackermann KG (Berlin). The logger measured the groundwater head every day. The groundwater heads of the shallow wells connected to the first, unconfined aquifer were measured manually every four weeks using a light plummet (gauge identifiers 199, 200 and 202). Due to the high variation of water levels in the case of prolonged dry periods, an automatic logger system was unsuitable in these wells. Table 2 provides an overview of the data base content.

3 Conclusions

The long-term measurement of geochemical and hydraulic parameters of groundwater properties is costly and time-consuming, but necessary in order to gain a deeper understanding of how the hydrological system works. This data base, including complex geochemical and hydraulic information, can therefore be used for further investigations regarding a 14 year period of groundwater data under changing hydraulic boundary conditions. The results ought to provide complex knowledge for evaluating and adapting land and water management for glacial landscapes in the Northern Hemisphere under the pressure of global change.

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4 Data access

The data used for the geochemical analyses is published under doi:10.4228/ZALF.2000.266. The data set contains 177 geochemical analyses of groundwater samples covering a wide range of environmental redox conditions. Data concerning the corresponding hydraulic conditions is published under doi:10.4228/ZALF.2000.272. The data set contains measured groundwater heads of two aquifers in different temporal resolution (1 day to 4 weeks).

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Table 1. Geochemical data base content and structure.

Column name	Parameter	Unit	Description
TIME			Date
GAUGE_ID			Identification of the gauge measurement
pH	pH value		pH value, measurement accuracy 0.01; WTW pH meter with pH probe; DIN 38404/5
Eh	Redox potential	mV	Redox potential, voltage, measurement accuracy 1 mV; WTW pH meter with a redox single-rod measuring cell; Eh by DIN 38404/6
CON	Electric conductivity	$\mu S\,cm^{-1}$	Electric conductivity, WTW conductivity meter with probe; DIN 38404/8
TEMP	Water temperature	°C	Water temperature, measurement accuracy 0.1 °C
O_2	Oxygen	$mg\,L^{-1}$	Oxygen, measurement accuracy 0.1 $mg\,L^{-1}$; WTW Oxygen meter; DIN 38408/22+23
NH_4	Ammonium	$mg\,L^{-1}$	Ammonium, calculated from NH_4-N
NH_4N	Ammonium nitrogen	$mg\,L^{-1}$	Ammonium nitrogen, measured, detection limit 0.01 $mg\,L^{-1}$; Photometer SPECORD 200; NH_4 by DIN 38406/5 (Na-salicylate method)
PO_4	Soluble reactive phosphorus (SRP)	$mg\,L^{-1}$	Soluble reactive phosphorus, calculated from o-PO_4-P
oPO_4P	Soluble reactive phosphorus (SRP)	$mg\,L^{-1}$	Soluble reactive phosphorus (only phosphorus without oxygen), measured, detection limit 0.01 $mg\,L^{-1}$; Photometer SPECORD 200; PO_4 by DIN 38405/11-1 (Molybdate method)
SAK	Spectral absorption coefficient	$1\,m^{-1}$	Spectral absorption coefficient, accuracy 0.01 nm, Photometer SPECORD 200; DIN 38404-3
Anions			(METROHM IC882) with column Metrosep A Supp 4–250/4.0
Cl	Chloride	$mg\,L^{-1}$	Chloride, detection limit 0.03 $mg\,L^{-1}$
Br	Bromite	$mg\,L^{-1}$	Bromite, detection limit 0.03 $mg\,L^{-1}$
NO_2	Nitrite	$mg\,L^{-1}$	Nitrite, detection limit 0.03 $mg\,L^{-1}$
NO_3	Nitrate	$mg\,L^{-1}$	Nitrate, detection limit 0.03 $mg\,L^{-1}$
SO4	Sulfate	$mg\,L^{-1}$	Sulfate, detection limit 0.02 $mg\,L^{-1}$
Cations			(METROHM IC882) with column Metrosep C 4–250/4.0
Na	Sodium	$mg\,L^{-1}$	Sodium, detection limit 0.01 $mg\,L^{-1}$
K	Potassium	$mg\,L^{-1}$	Potassium, detection limit 0.02 $mg\,L^{-1}$
Mg	Magnesium	$mg\,L^{-1}$	Magnesium, detection limit 0.02 $mg\,L^{-1}$
Ca	Calcium	$mg\,L^{-1}$	Calcium, detection limit 0.03 $mg\,L^{-1}$
DOC	Dissolved organic carbon	$mg\,L^{-1}$	Dissolved organic carbon, detection limit 0.05 $mg\,L^{-1}$
Fe(II)	Iron(II)	$mg\,L^{-1}$	Iron(II) Fe^{2+}, detection limit 0.03 $mg\,L^{-1}$; ICP-AES with atomizer; Optical emission spectroscopy
Mn	Manganese	$mg\,L^{-1}$	Manganese, detection limit 0.05 $mg\,L^{-1}$; ICP-AES with atomizer; Optical emission spectroscopy
HCO_3	Hydrogen carbonate	$mmol\,L^{-1}$	Hydrogen carbonate, accuracy 0.01 $mmol\,L^{-1}$; titration with SCHOTT Titroline 96

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Table 2. Hydraulic data base content and structure.

Column name	Parameter	Unit	Description
TIME			Date
GAUGE_ID			Identification of the gauge measurement
WPNlog	Groundwater head	m a.s.l.	Groundwater level below surface, measurement accuracy 1 mm; automatic datalogger ACKERMANN KG (Berlin, Germany)
WPN	Groundwater head	m a.s.l.	Groundwater level below surface, measurement accuracy 1 mm; measurement with light plummet

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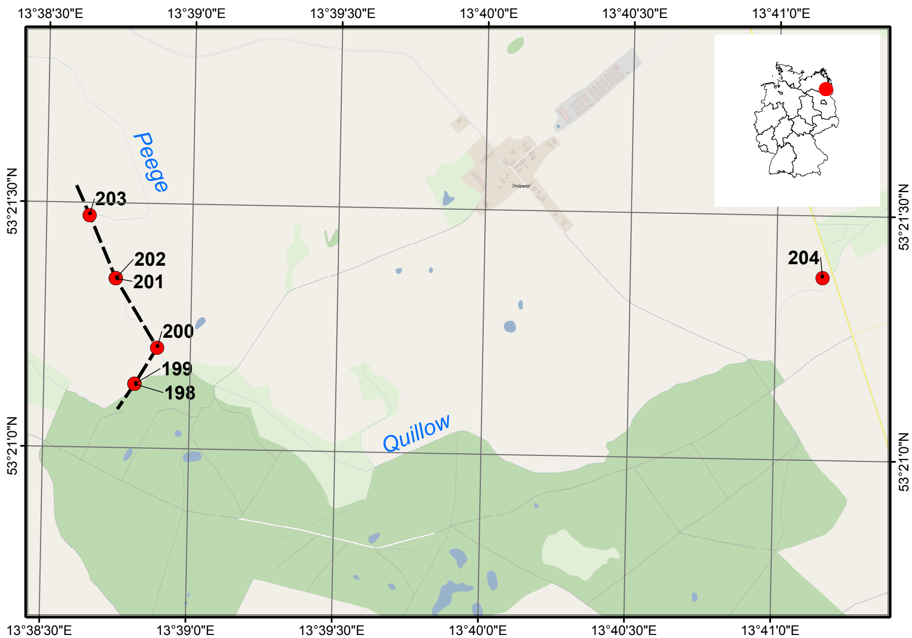

Figure 1. Location of the Quillow catchment and location of the sampled groundwater observation wells, transect of geological profile indicated.

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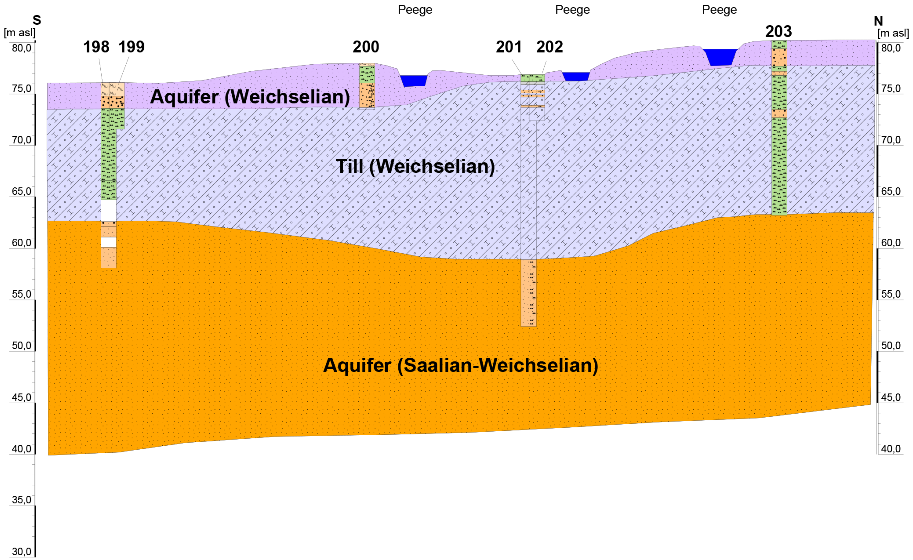

Figure 2. Geological profile of the sampled transect with location and depth of the groundwater observation wells.

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