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Aquifer storage and recovery: a feasibility study

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Abstract Aquifer Storage and Recovery (ASR) is a water management technology in which an amount of water is pumped into and stored underground in a suitable aquifer during times of surplus, and recovered in times of shortage. If treated water is pumped in, a drinking water bubble, with a certain volume, is created underground and will be available for direct use when needed. The aquifer needs to be prepared to minimize the potential of water quality change during storage. The practical experience of a two-year deep infiltration test at the site of Dizon was used to design the ASR experiment at Herten, The Netherlands.

Key words aquifer storage and recovery; water management technology

INTRODUCTION

Aquifer Storage and Recovery (ASR) is a water management technology in which a pumped volume of water is stored underground in a suitable aquifer during times of surplus and recovered in times of shortage. In October 2000, the Water Supply Company of Limburg (WML; The Netherlands) started the first ASR test cycle by infiltration of fresh drinking water through one experimental ASR well that is used for both injection and recovery. Several ASR sites are in operation in the United States of America; however, this is one of the first experiences with ASR in a European country. WML has been considering ASR to meet peak demands within its supply area, since 1998 and has selected an aquifer at Herten, applied for a permit and built a test site. ASR at WML will be feasible if no re-treatment of the infiltrate is necessary. Therefore, the aquifer needs to be prepared to minimize any mineral reactions with the potential to change water quality during storage. Preparation will take about ten cycles of infilt-ration and recovery. This paper describes the research undertaken to investigate basic assumptions, some practical experience of deep infiltration, and the results of the first ASR cycle at Herten. This first cycle is part of a two year feasibility research programme of six to eight cycles. In two years the project will be evaluated and WML will decide whether ASR is feasible for the coming decade.

DEEP INFILTRATION STAGNANT TEST AT DIZON, SOMEREN

The practical experience of a two year deep infiltration test at the nearby site of Dizon was used to design the ASR experiment at Herten. The hydrochemical characteristics of this aquifer were used to determine the radius of the ASR bubble to create, and the distance between two observation wells at the Herten site. The breakthrough times (t_{br})

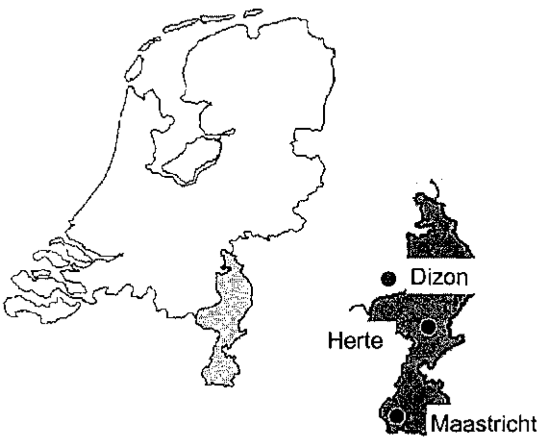

Fig. 1 Location of Dizon and Herten sites.

of the redox parameters (i.e. the positions of the observation wells for measuring break-through) were estimated from the number of pore flushes (*ADP*) from the Dizon site using the formula: $t_{br} = (\pi r^2\ Th\ \varphi\ ADP)/(24Q)$, where ADP = number of pore flushes, φ = porosity, Th = aquifer thickness [m], r = oxic bubble radius [m], Q = infiltration/recharge [$m^3\ day^{-1}$].

After the deep infiltration test at Dizon had terminated, three months of measurement gave information as to the sustainability of the oxygen bubble at 300 m depth below the surface (Fig. 2(a–c)). During the two years of infiltration, oxic surface water infiltrated into the aquifer and created an oxic zone across the profile.

The measurements show that oxidants were depleted after three months and iron (hydr)oxides and sulphides were reducing along the infiltration well, which resulted in an increase of dissolved iron content. The state of mixing oxic zoning around the well can cause clogging when recharge is taking place, therefore detailed monitoring is useful to estimate cycle duration and intervals.

HYDROCHEMICAL ISSUES AT THE ASR SITE AT HERTEN

The target aquifer is a 10 m thick unconsolidated sandy sediment with pyrite (Brunssum Formation) and is confined between two clay layers. The pumping test showed an average transmissivity of 280–300 $m^2\ day^{-1}$, which implies a permeability of <40 m day^{-1}. No clogging has been registered to date. In order to store 150 000–200 000 m^3 of drinking water annually, the diameter of the oxic water bubble has to be 250–290 m. The infiltration rate is 50 $m^3\ h^{-1}$, and no chlorine is injected to prevent clogging.

The aquifer is deeply anoxic with no dissolved sulphate, but a high iron content (7–14 mg Fe l^{-1}) and high acid buffering capacity (320 mmol $HCO_3\ l^{-1}$). Core samples were taken from the observation well and investigated for mineral content. The aquifer contains clayey layers and organic matter (gyttja) along the profile. The iron oxides, mainly situated in the clayey layers, are amorphic and very reactive, which may have a negative impact on water quality. High pyrite contents were found in the clay (using a

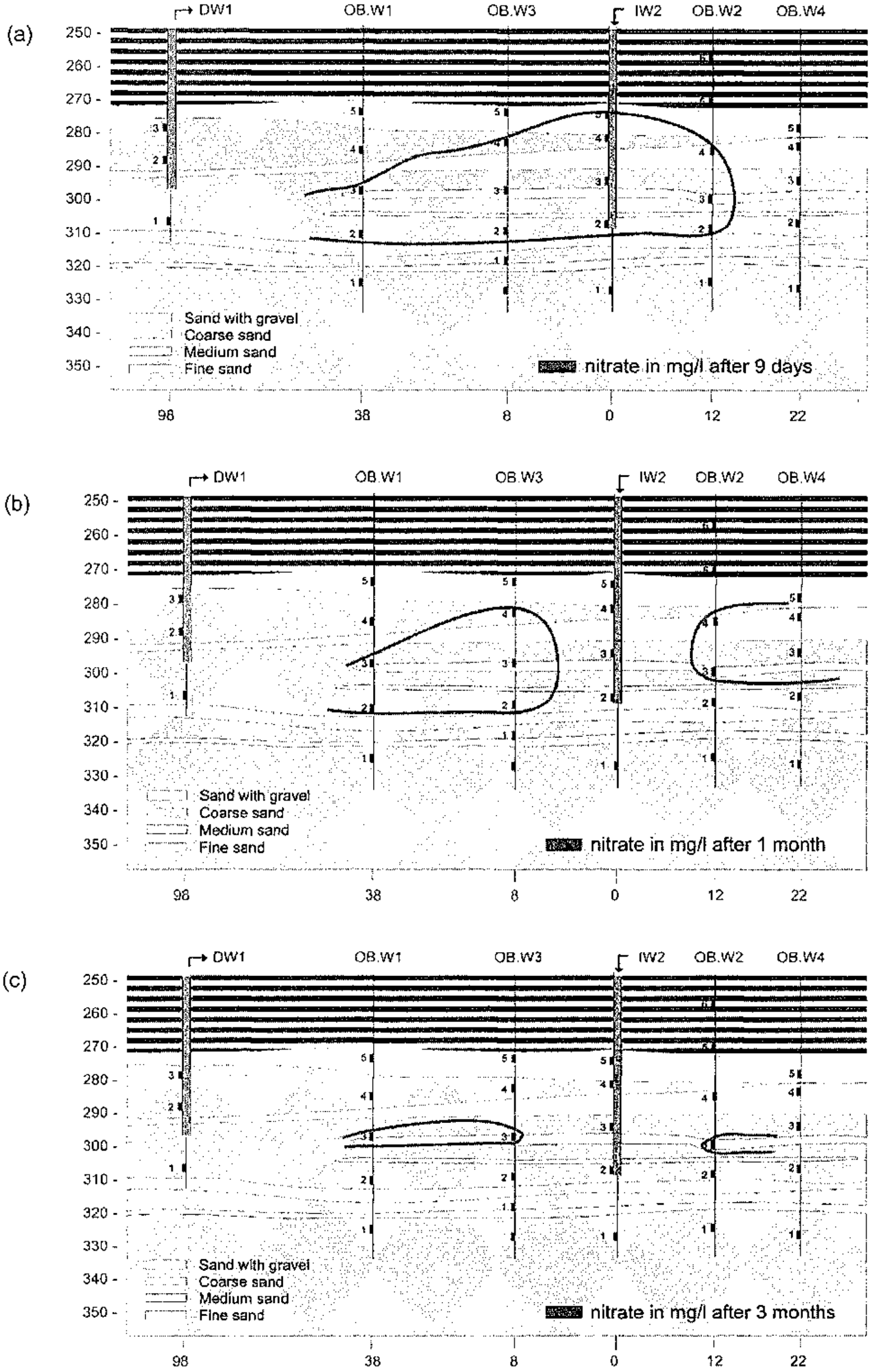

Fig. 2 Redox-zoning during stagnation test: (a) nitrate bubble after nine days of stagnation; (b) after one month of stagnation; and (c) after three months.

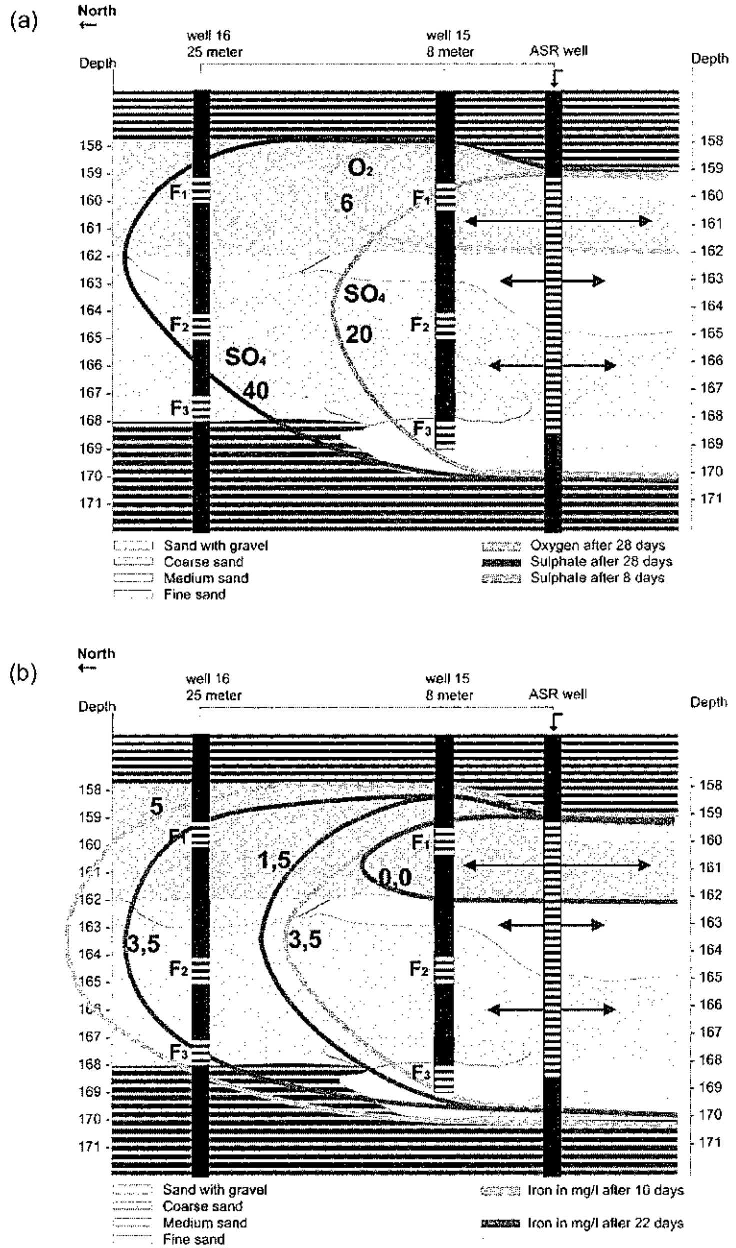

Fig. 3 (a) Breakthrough of the oxic front after 28 days (oxygen 6 mg l^{-1}, sulphate 40 mg l^{-1}) and 8 days (sulphate 20 mg l^{-1}). (b) Isolines of iron immobilization after 10 days (iron 3.5 and 5 mg l^{-1}) and 22 days of infiltration (iron 0, 1.5 and 3.5 mg l^{-1}).

sequential extraction method) so that a pH increase and iron contribution from pyrite oxidation may be expected to frustrate ASR applications. Compared to the sand layers with low reactivity, high siderite and calcite contents are found in the clayey layers, which may be a positive factor in neutralizing any pH increase. The cation exchange complex is dominated by Ca^{2+} (90%) and Mg^{2+} (10%). Exchange with Na^+, K^+ and H^+ can take place, which may increase total hardness. Aside from well sampling, more detailed mass balance and transport modelling is planned to predict further cycle recovery. Kinetic constants will be derived from the oxygen flushing experiments on the core samples.

RESULTS OF ASR, FIRST TEST CYCLE AT HERTEN

After one month of infiltration the results indicated that a three month infiltration period was needed to obtain sufficient breakthrough at a distance of 25 m from the ASR well, and to precipitate iron and manganese hydroxides (Fig. 3(a,b)).

Chloride moved twice as fast as sulphate. Sulphate breakthrough was measured after two days in observation well 15 (OBW15) at 8 m from the ASR well. After one week, 20 mg l^{-1} was measured in OBW15 and after one month 40 mg l^{-1} was measured in OBW 16 at 25 m from the ASR well. Oxygen breakthrough was first measured after one month in OBW15 filter one, as a result of higher permeability in the upper part of the profile. Similarly precipitation of iron (hydr)oxides was interpreted by a decrease of iron. In order to speed up preparation of the aquifer, extra oxidants will be added in the next cycles and accelerated oxidation of minerals will be investigated. Also well clogging, infiltration and discharge rates and the cycle intervals will be subjects of interest during this programme.