Artificial Recharge of Fresh Water in the Belgian Coastal Dunes

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ABSTRACT

Since July 2002, the Intermunicipal Water Company of the Veurne region (IWVA) artificially recharges fresh water in the dunes of the western Belgian coastal plain by means of two recharge ponds. This recharge water is produced from secondary treated waste water effluent by the combination of ultra filtration and reverse osmosis. The artificial recharge project loops the water cycle: extracted water goes to the users and their waste water is purified and re-used. In this paper, the results of simulations of the artificial recharge are discussed and descriptions of the hydrochemistry of dune water, recharge water and extraction water are given. This artificial recharge project is an example of sustainable water management in coastal aquifers.

INTRODUCTION

The dunes of the western Belgian coastal plain are of importance as source of fresh water. In the surrounding areas (sea, shore and polder) mainly brackish to salt water is found. Otherwise, fresh water lenses which are present in the polder contain very limited fresh water resources (Vandenbohede and Lebbe, 2002). Groundwater exploitation in the dune aquifer for the production of drinking water started in 1947 at the water extraction site St-André by the Intermunicipal Water Company of the Veurne region (IWVA). The IWVA is responsible for the distribution of drinking water in the western part of the Belgian coastal plain. The extraction rate rose steadily from about 0.5 million m³/y during the 1950s to 1.75 million m³/y during the 1960s. From then on extraction rate fluctuated around 2 million m³/y up to the second millennium. Initially the water extraction started with one well battery with 109 wells. In 1968, a second well battery was put in use with 54 wells. Extraction rates of both well batteries were more or less the same. Extraction wells have screens between 6 and 10 m below surface or between 12 to 16 m below surface. In 2002, 70 wells were active with the first well battery and 112 wells with the second well battery. To ensure a water extraction which meets the demands and preserve further the ecological values of the dunes, it was decided to artificially recharge the dune aquifer. This started in July 2002 and is an example of sustainable water management in coastal aquifers. The aim of this paper is to illustrate some characteristics and benefits of the artificial recharge project.

The system which is used consists of two ponds which are in the centre of the wells of well battery 2 (figure 1). The two ponds are connected to each other through a pipe. The recharge water is effluent from a nearby waste water treatment plant. Before recharge, this effluent is further treated using ultra filtration (UF) and reverse osmosis (RO) (Van Houtte and Verbauwhede, 2005). The recharge water is thereafter extracted via the wells of well battery 2. These wells are situated north and south of the ponds. The artificial recharge project loops the water cycle: extracted water goes to the users and their waste water is purified. After UF and RO treatment, this water is recharged in the dune aquifer and can be reused. Up to 2.5 million m³/year can be recharged and the same amount of water can be extracted. Additionally 1.7 million m³ natural dune water can be extracted (1 million by well battery 2 and 0.7 million by well battery 1). This means that the capacity of the water extraction has more than doubled (from 2 million to 4.2 million m³/year) whereas the net amount of water extracted from the dune aquifer is reduced from 2 million to 1.7 million m³/year. This way of reusing limited fresh water resources in a sustainable way remains up to the present day a unique system in Europe.

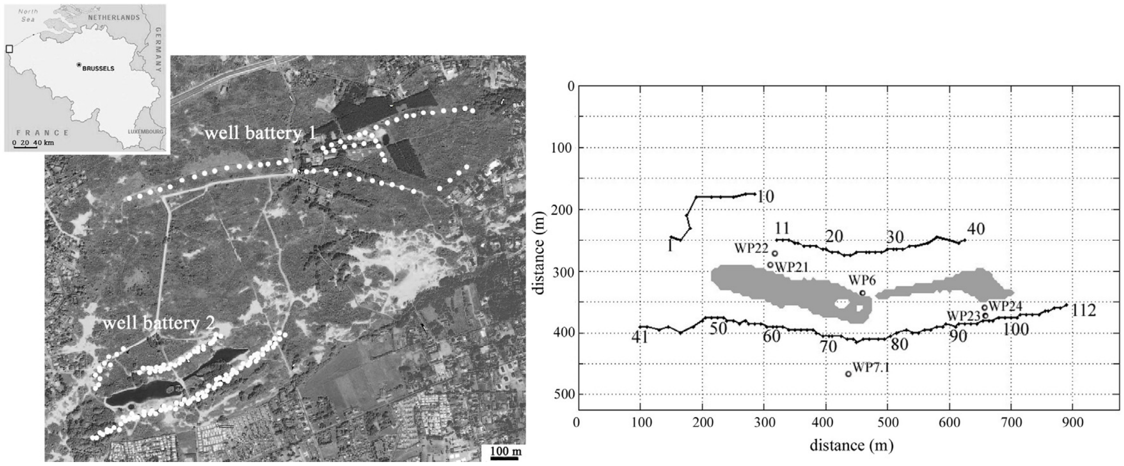

Figure 1. Location of the St-André water extraction in the dunes of the western Belgian coastal plain. Location of both well batteries and the artificial recharge pond between the wells of well battery 2 are indicated. Right figure gives a detailed overview of the location of wells of well battery two, the two ponds and some observation wells.

GROUNDWATER FLOW MODELLING

Since July 2002, a large number of data (hydraulic heads; water quality data of recharge water, extraction water and groundwater; borehole measurements, tracer tests) has been gathered. The combination of these different data sets give a unique insight in the hydraulics and hydrochemistry in the vicinity of recharge ponds and the water extraction. First step in the analyses of the data is the construction of a groundwater flow model. This was done in two steps. In first instance, a regional density dependent flow model of the dunes and neighbouring sea and polders was made (Vandenbohede et al., in review a), using MOCDENS3D (Oude Essink, 1998) and the Visual MOCDENS3D user interface (Vandenbohede, 2007). The model measures 4200 by 4500 m and includes the quaternary phreatic aquifer. The aquifer is subdivided in 12 layers, 60 columns and 56 rows (height 2.5 m, width and length 75 m) resulting in 40320 finite difference cells. The natural salt-fresh water distribution is calculated after which the extraction history up to the present day is included in the model. Artificial recharge results in a general increase in fresh water heads corresponding to the situation in 2002. In the vicinity of the infiltration ponds there is an important increase of the fresh water heads. Also of importance is the fact that the natural flow of fresh water from the dunes towards the sea and the polder is restored in large parts of the aquifer. This flow was importantly reduced before the artificial recharge project. In second instance, a more detailed model was made of the vicinity of the ponds (Vandenbohede et al., in review b). This model measures 975 by 525 m and consists of 105 rows and 195 columns. Dimension of every finite-difference cell is 5 by 5 m and 12 layers are considered each with a thickness of 2.5 m. The boundary conditions of this model are derived from the larger regional flow model. This model shows the increase of the amount of recharged water (about 50 mg/l) in the fresh ground water (about 550 mg/l). Modelling shows further that the depth of the lens of recharge water under the eastern pond is slightly less than 20 m whereas this is slightly more than 20 m for the western pond. This was confirmed by geophysical borehole measurements. Because of its larger surface, more recharge water is present under the western than under the eastern pond. Groundwater flow and flow paths show that the occurrence of recharge water is not restricted to the zone between the ponds and the extraction wells, especially around the western pond. Water flows south of the southern wells of well battery 2 before flowing back to the extraction wells. This is due to a shallow semi-permeable layer which is present below the western pond. However, this does not mean that not all recharge water is not recovered since flow paths show that all recharge water flows towards the extraction wells. This was also confirmed by comparing chloride concentrations in dune water, recharge water and extraction water. Analysis of residence times have indicated that 50% of the water recharged at one instance reaches the extraction wells in less than 60 days. It takes up to almost 5 years for the last water which was recharged at one instance to reach the extraction wells. These calculations are confirmed by the results of a tracer test. The distribution of residence times indicate that the water which is extracted is a mix of water with a wide range of residence times, ranging from slightly less than 30 days up to almost 5 years. Large residence times are the result of water which flows in a longer and deeper flow cycle towards the extraction wells. The spread of the residence times, together with the fact that also native dune water is extracted (80% recharge and 20% native dune water) makes water quality of the total extraction water stable throughout the year.

HYDROCHEMISTRY

Four different water types were recognized in the aquifer (Vandenbohede et al., in review c). First water type is the dune water. The native fresh water is a $F2CaHCO_3Ø$ water type, using the Stuyfzand classification (1993). Mean TDS of shallow natural dune water is 550 mg/l whereas this is 800 mg/l for deeper dune water. The second water type is the extraction water. This water is a mixture of dune water (20%) and recharged water (80%). This mixing is, however, highly dependent on the recharge and extraction rates. Water extracted before May 2004 is a $F2CaHCO_3Ø$ water type, thus the same water type as mean shallow dune water. After May 2004, AR water became less mineralised and this is also reflected in the extracted water which becomes a $g2CaHCO_3Ø$ water type. This difference is due to a change in the production process of the recharge water. Third water type is the artificial recharge water. The artificial recharge water before May 2004 was g0NaMixØ type before May 2004 and becomes a $G0NaHCO_3Ø$ water type afterwards. TDS of the recharge water is very low in comparison with the dune water. Fourth water type is the artificial recharge water which is present between the recharge ponds and the extraction wells. During passage through the aquifer to the extraction wells, the recharged water is mineralised mainly by carbonate dissolution and is thus importantly enriched by calcium and bicarbonate and in a lesser extent by magnesium, potassium and fluoride. Although it can not be excluded that cation exchange also occurred, carbonate dissolution is the main process determining the remineralisation of the recharge water. Redox reactions are a second important process due to the artificial recharge of oxygenated water in a mainly anoxic aquifer. Oxygen in the recharge water is relatively quickly consumed. Also, nitrate is oxidized. Concentration of iron and sulphate is increased because of oxidation of iron sulphide minerals. Oxidation of manganese minerals results in an increase of the latter concentration.

CONCLUSIONS

The experience gained with the artificial recharge of tertiary treated waste water in the dunes led us to conclude that this is a very interesting method to assure a sustainable drinking water production. It resulted in an increase of the capacity of the extraction although a decrease of the extraction of natural dune water is achieved. Consequently, hydraulic heads and groundwater flow in the dunes are partly restored. The extracted water is a mix of recharged and native dune water and concerning the recharge water a mix of water with different residence times. This results in a stable quality of the extracted water.

REFERENCES

Oude Essink GP (1998). MOC3D adapted to simulate 3D density-dependent groundwater flow. In: Proc. of MODFLOW ’98 Conference, October, 4-8, 1998, Golden, Colorado, USA, Volume I, 291-303.

Stuyfzand, P.J. (1993). Hydrochemistry and Hydrology of the Coastal Dune area of the Western Netherlands. Ph.D. Thesis, Nieuwegein, KIWA, Afd. Onderzoek & Advies.

Vandenbohede A and Lebbe L (2002). Numerical modelling and hydrochemical characterisation of a fresh water lens in the Belgian coastal plain. Hydrogeology Journal, 10(5), 576-586.

Vandenbohede, A. (2007). Visual MOCDENS3D: visualisation and processing software for MOCDENS3D, a 3D density dependent groundwater flow and solute transport model. User Manual. Research Unit Groundwater Modelling, Ghent University.

Vandenbohede, A., Van Houtte, E. and Lebbe, L. (in review, a). Sustainable groundwater extraction in coastal areas: a Belgian example. Environmental Geology.

Vandenbohede, A., Van Houtte, E. and Lebbe, L. (in review, b). Groundwater flow in the vicinity of two artificial recharge ponds in the Belgian coastal dunes. Hydrogeology Journal.

Vandenbohede, A., Van Houtte, E. and Lebbe, L. (in review, c). Water quality changes in the dunes of the western Belgian coastal plain due to artificial recharge of tertiary treated wastewater. Applied Geochemistry.

Van Houtte E and Verbauwhede J (2005). Artificial recharge of treated wastewater effluent enables sustainable groundwater management of a dune aquifer in Flanders, Belgium. Proceeding Ismar 5, 5th International Symposium on Management of Aquifer Recharge Systems for protecting and Enhancing Groundwater Resources, 10-16 June 2005, Berlin.

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