Urban Groundwater Management as Risk Reduction Tool for Groundwater Extractions

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Abstract. In the urban area of Rotterdam many different groundwater extractions take place, which affect the groundwater system. Urban groundwater management is a tool to prevent the risk of non-intended effects of these extractions and unsustainable use of groundwater. The main goal is to exchange information and knowledge for a better understanding of the groundwater system and an integrated approach when regarding and authorizing the different functions of groundwater.

Keywords. groundwater extractions, delta area, urban groundwater management, sustainability

1. Introduction

Extracting groundwater often causes risks for the natural or urban environment, like subsiding of the subsoil, moving contaminated groundwater or influencing other groundwater extractions. An important element of these risks is the fact that urban groundwater is part of a complex and sensitive system. Groundwater has many different functions and many stakeholders are involved with it. Reducing the risks related to groundwater extractions is not primarily a matter of technical measures in projects, but starts with the exchange of local information and experience.

In the Netherlands, the legislation of activities in the groundwater system is spread over different authorities: waterboards, Province and municipality. Each of these authorities plays its own role. The Provinces are responsible for the quantity and quality of regional groundwater bodies in the context of National and European legislation, but the operational management is done by the waterboards. A similar dichotomy occurs in the authorisation of groundwater extractions: the Province is responsible for the large, industrial extractions and shallow geothermal energy systems, but the Waterboards are responsible for the other groundwater extractions. The city council has a legal duty of care for the groundwater system. In public space, if groundwater levels are structurally too high or too low, causing difficulties in the designated use of the area concerned, the municipality is obliged to commit effort in taking measures, providing that these measures are expedient (cost-effective). Residents are responsible for the groundwater level at their private owned lot.

There is a lot of knowledge about and experience with groundwater in the urban area, but it is spread over multiple parties. Urban groundwater management is a tool to achieve cooperation and coordination between the authorities concerned.

This article describes how urban groundwater management was started in Rotterdam. Further on, some cases are described whose problems concerned with groundwater extractions and a focus on the exchange of information between the stakeholders.

2. Starting Groundwater Management in Rotterdam

Area-specific groundwater management is a policy concerned with integral and sustainable groundwater management in a restricted area. Groundwater activities and interventions in the groundwater are linked to environmental goals, nature and spatial and economic developments, to be carried out for the long term. In most cases, the main focus of area-directed groundwater management is on historic groundwater contamination.

In Rotterdam, the municipality, three waterboards that operate in this region, and the
Province of South-Holland together investigated a way to introduce area-restricted managing of groundwater contamination. The investigation showed that at present there are no major problems regarding groundwater contamination in the urban area for the further development of Rotterdam, which made area-specific groundwater management in the strict sense unnecessary. It was decided however to sign a Motivation of Understanding (MoU) to strengthen cooperation between the authorities in the field of groundwater.

With the MoU, the participants speak up for better collaboration and sharing of knowledge and information about the groundwater system. This reduces the risk of problems due to too high or too low groundwater levels.

The Memorandum contains specific agreements of cooperation between the Authorities concerned with groundwater. For example the waterboards will take a greater account of urban vegetation in the authorisation of groundwater extractions. On the other hand, the municipality will involve the expertise of the waterboards in the preparation of spatial plans. The quality of the groundwater is also taken into account; for example the discharge of rainwater in deep aquifers which may deteriorate the quality of deep groundwater.

The partnership will be further worked out in the Rotterdam ‘Vision of the underground’ in which groundwater plays an important role.

3. Fire Extinguisher Water

3.1. Fire Extinguisher Wells

Throughout the city of Rotterdam one can find many wells from which the fire department can pump up fire extinguisher water. The primary sources of fire extinguisher water are hydrants connected to the drinking water supply. Due to quality standards the water company tends to install pipes with smaller diameters. This means that the secondary source of fire extinguisher water from drilled wells becomes more and more important. The main requirement is that a fire extinguisher well should provide a water flow of 90 m³/hour for at least 4 hours continuously.

Urban developments and large buildings should provide enough wells for fire extinguisher water to guarantee the safety in case of fire. An interesting detail is that the extraction of groundwater for fire extinguisher water is not authorized by an extended procedure of the national Water Law, because it’s an emergency supply. For other large groundwater extractions an extended procedure is obligatory; which requires an extensive study of impact on the groundwater system and the (urban) environment.

3.2. Rotterdam Railway Station

In the city centre of Rotterdam, a new railway station was opened in 2014. The fire department claimed that close to the railway terminal building at least four wells should be situated, plus four wells at the east and four at the west end of the railway emplacement (Doelder, 2011).

The Municipality of Rotterdam was involved in many projects around the Central Station. The Project Management and Engineering Department therefore knew the risks of large groundwater extractions in this area. The Dutch national railway company decided to use the experience of Rotterdam to investigate the best locations and dimensions for these fire extinguisher wells.

The first idea was to drill several wells to the first aquifer. Figure 1 shows the layout of the wells.

![Figure 1. Overview of locations for fire extinguisher wells at Rotterdam Central Station](image)

The first aquifer consists of coarse sand of Pleistocene ages, situated between approximately 15 and 30 m below ground level. This aquifer is very convenient for supplying the demanded flow, but, as discussed below, extracting this amount of water will introduce two risks:
structural damage to the subway tunnel and subsidence of foundations of nearby ancient buildings, especially private homes in the Provenierswijk.

The geohydrological system at the project area of Rotterdam Central Station is rather complicated. It consists of an anthropogenic layer on the 10 to 20 m thick Holocene layer. Below there is the first aquifer, made up of Pleistocene River deposits with a thickness of 15-20 m. Underneath the Pleistocene aquifer there is first a separating layer and the second aquifer. The Holocene layer mainly consists of clay and peat, functioning as a confining layer. However, at this specific location well drained sandy river dune deposits can be found, which are in contact with the underlying Pleistocene aquifer locally.

Furthermore, in the station square’s subsoil a former canal is present, which is partly filled up with sandy material (Doelder & Hannink, 2015). This canal holds the subway tunnel which was opened in 1968. At the location of the highrise office building “Delftse Poort” (Nationale Nederlanden) this sand canal intersects with the river dune deposits in the Holocene layer, therefore indirectly connecting with the Pleistocene layer. As a result, a groundwater extraction in the first aquifer leads to a lower phreatic level in the sand canal. The pile foundation of the subway tunnel is depending on a certain upward ground water pressure. If the phreatic water table beneath the subway tunnel falls below NAP -3.3 m, a serious risk of structural damage at the tunnel foundation arises.

In the area around the central station, earlier groundwater extractions from the first aquifer occurred. To prevent damage of foundations, the reduction of the water level in the first aquifer should not be more and should not last longer than occurred in the past. Although the groundwater extractions do not last long, the wells shall frequently be tested which gives a frequent water pressure reduction. This means that the hydraulic head should not be lower than NAP-6.4 m, a reduction of approximately 4 m.

At first, a groundwater model showed that an extraction from 4 wells close to each other in the first aquifer over a period of 4 hours could result in too much reduction of the hydraulic head in both phreatic layer and first aquifer.

An alternative was found in drilling the fire extinguisher wells in the combined second and third aquifer, at a depth between NAP -52 m and NAP -202 m (Niewold, 2012). In this layer several wells for geothermal energy systems are situated. The extraction of fire extinguisher water can affect the storage of thermal energy by translocating the amount of stored cold or warm water, resulting in a less-efficient energy storage system.

The final design of the wells near the terminal was found in three wells in the first aquifer, with a capacity of 120 m$^3$/hour with greater distance in between the wells than in the first plan.

3.3. Highway A15

National highway A15 runs at the southern edge of Rotterdam, towards the harbour area (fig. 2). A large stretch of this highway will be improved and widened, which has been realized in the A-Lanes project since 2011. Part of this project was the installation of 28 fire extinguisher wells.

Some of these wells are situated south of the Botlek area (the blue part in Figure 2). The Botlek area is a large-scale industrial area, in use for chemical industry since 1960. Because of this long history, large-scale and complex contamination of groundwater can be found here. Since 2011, the city of Rotterdam is involved in the ‘Pilot Botlek’, a pilot project for introducing area-restricted management of the contaminated groundwater. Part of this project is the controlled spreading of contaminated groundwater within a restricted area, using natural attenuation. A groundwater model is used to calculate the development and degradation of plumes of contaminated water.

In 2013, A-Lanes reported the installation of the required wells for 28 fire extinguisher water wells along the A15 to the local Waterboard (Borsboom, 2012). The Waterboard and the
Project Management and Engineering Departments of the Municipality of Rotterdam agreed to share all applications and permissions for groundwater extractions. As a result, Rotterdam took notice of these plans for fire extinguisher wells and compared them with the model results for the contaminated groundwater from Botlek. Some of the wells were located close to the developing plumes. Extracting groundwater at these locations would influence the spreading of contaminated groundwater. Rotterdam advised that they should be relocated to a place outside of the contaminated area.

4. Groundwater Extractions for Building Activities

In Rotterdam, an excavation for building activities can only maintain geotechnical stability when the relatively high hydraulic head in the first aquifer is reduced by a groundwater extraction. Due to the high permeability of this aquifer, such an extraction tends to have a large area of hydraulic influence, in many cases some kilometers wide. To get permission for these activities, the national Water Law requires a thorough impact study. The main risk for the urban environment is failure of ancient pile foundations due to the increase of downward forces from the surrounding, subsiding soil. Simultaneous extractions influence each other and can lead to critical situations as the hydraulic head will be reduced too much. Especially when an extraction is not automatically controlled by measuring the groundwater level, but only by the pumped amount of water, the risks for the urban environment can increase. When structural damage occurs its hard to point out which groundwater extraction did cause this damage. Another risk occurs when an extraction is finished and the pumps are turned off. This leads to a sudden increase of hydraulic head, which can result in uplift of an excavation. On the other hand, simultaneous groundwater extractions give the opportunity to reduce the volume of pumped groundwater and can reduce or minimize the overall negative influence on the urban environment, while the period of decreased hydraulic head will become shorter.

Coordination of simultaneous extractions is indispensible for connecting the different stakeholders for exchanging information of their activities. It calls for a pro-active attitude of the involved authorities. The municipality of Rotterdam in some cases acted as coordinator, but possibilities are limited as the Waterboards are authorized according to the national Water Law.

5. Shallow Geothermal Energy

The subsurface of the Rotterdam area is appropriate for the use of shallow geothermal energy (SGE). In the city centre, aquifer thermal energy systems are commonly used for the heating and cooling of large offices and tall apartment buildings. The working principle of such a system is shown in figure 3.

Using SGE gives a serious reduction of energy use compared to conventional energy sources. As the city of Rotterdam is committed to achieve a reduction of 50% in CO₂ emission, the city promotes the use of sustainable energy for heating and cooling of buildings.

Aquifer thermal energy systems are not allowed in the first aquifer (between approximately NAP -15 m and NAP -35 m) in urban areas to avoid risks for foundations and the urban water system.

In Rotterdam City Centre the demand for SGE is high, but the energy storage capacity of the concerning aquifer is limited. Improvident placement of a system is a risk for future and sustainable use of the groundwater. Rotterdam
designed a detailed SGE plan created for this area (Boer, 2013). It indicates distinctive areas for the positioning of the groundwater wells and their area of geothermal influence, which may not reach outside a calculated contour (fig. 4). In addition, the plan takes account of future users and other subsurface interests. Because it is based on using the entire thickness of the aquifer, the energy storage capacity is used as efficiently as possible.

**Figure 4.** Part of the map of the SGE plan for Rotterdam City Centre

Outside the city centre, general rules are formulated for the distance between warm and cold wells. This prevents the generation of ‘white’ areas, which are too small to place another well in, thus implying that not the whole aquifer can be used.

Using the SGE plan, initiators of new SGE-systems are forced to make deeper boreholes with a narrower area of geothermal influence, leaving more room for future systems.

The Province is the legal authority for permission for SGEs, whereas the Municipality of Rotterdam is involved with urban development projects. Developing a SGE plan can only be realized with a close cooperation between both authorities, focussed on a sustainable use of the groundwater system.

### 6. Conclusions

The cases described in this article show clearly that the functions of groundwater are diverse and many stakeholders are involved. Due to the geological history of the subsoil and human building activities, the groundwater system can be quite complicated. Groundwater extraction can therefore lead to unexpected effects for the urban environment. Local information of the subsoil, the groundwater system and existing buildings are indispensible to avoid the risk of damage of nearby structures. Exchange of this information in an early stage of the project is indispensable for risk management.

The exchange of knowledge therefore is the primary goal of signing a Memorandum of Understanding in Rotterdam by the municipality, three Waterboards and the Province of South-Holland.

Urban groundwater management implies coordination of activities which affect the groundwater system, especially simultaneous groundwater extractions. It calls for a pro-active attitude of the authorities, which might reach beyond legal responsibilities. The Municipality of Rotterdam is willing to play a coordinating role, within a framework of urban groundwater management.

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