Sustainable synergies for the subsurface; combining groundwater energy with remediation, an illustration with 2 cases

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Abstract:
In the recent past, the shift to more sustainable energy sources has resulted in a significant increase in the application of Heat Cold Storage (HCS) in groundwater in the Netherlands. Currently, about 1.000 systems exist, and this is expected to increase to approximately 20.000 in 2025. HCS initiatives are often used in dynamic urban areas (inner cities), where groundwater contaminants are also present. In a strict interpretation the Dutch Soil Protection Law prohibits the (additional) movement of contaminants. As the application of HCS is dependent on high groundwater flow rates and volumes, HCS in or near contaminants presents a challenge.

In the last decade, the policy on largely contaminated areas has moved from a case-based approach aimed at multifunctional use of groundwater to risk based groundwater management. Higher environmental goals (at a more holistic level) are also regarded nowadays, and what used to be a bottleneck is starting to be regarded as an opportunity to combine the remediation of contaminated areas with sustainable energy. Sensible use of the subsoil can lead to profit, and can also be a means to protect and improve soil and groundwater quality. HCS systems can be used to contain, control or sustainably remediate groundwater. In this abstract two different, real life approaches are illustrated for the combination of and interactions between Heat Cold Storage and remediation. These examples illustrate the shift towards sustainable use of groundwater, a means of improving groundwater quality.

CASE 1:
SANERGY; THE SYNERGY OF REMEDIATION AND SUSTAINABLE ENERGY

1.1 Introduction

Figure 1: The Strijp-S site with historical buildings

Sustainable redevelopment

The former Philips Site in Eindhoven used to be the cradle of innovation. Philips started its activities at this site in 1915, and within 15 years this 27 hectares site was completely built on. At it's peak more than 10.000 people were working at Strijp-S. Currently the site is being redeveloped; historical buildings will receive new functions, and new buildings and houses will be erected in a huge urban redevelopment project.

As a result of decades of industrial activity, soil and groundwater at the site are contaminated to a depth of 60-70 m-bgs with chlorinated solvents. In the planning stage, very ambitious criteria were formulated for sustainability. A sustainable society is one of Philips' missions, and in 2004 they introduced their intention to combine groundwater remediation with groundwater energy. This was the first time in Dutch history that the idea of combining these two worlds was brought forward. The site and its surroundings are an example and cradle for innovation once again.

Combining different worlds, from paradoxes to synergy

The combination of the world of sustainable energy and remediation and their objectives entails a paradox. Sustainable energy can be obtained from groundwater by pumping large flows and extracting heat or cold with a heat pump. The aim of a groundwater energy system is to maximise the energy capacity, which demands large groundwater flows. This is the first paradox with the remediation of groundwater. Normally the remediation of contaminated groundwater is designed with minimal flows to reduce waste volume and thus cost. The second paradox lies in the containment of groundwater. Within the traditional approach with Heat-Cold-Storage (HCS), groundwater is pumped from a cold zone to a warm zone. With such an approach contaminants are moved and spread as well. A remediation system is primarily designed to contain and reduce the extent of contaminants.

Synergy of these worlds is possible if the necessary large flows are used to contain the contaminants.

More challenges

Being the first to draft and engineer such a groundwater system means that many possible bottle-necks have to be anticipated. Durability of the energy system demands continuous groundwater pumping and the risk of well clogging. Combining two worlds also entails working with different authorities and the gearing of permits. A remediation permit falls under the jurisdiction of the municipality while the groundwater permit is the responsibility of the Province.

Last but not least; the engineering of the groundwater and energy system itself is a challenge; the total flow in the extraction wells is dominated by the energy demand in the buildings. On the other hand these flows must be used to contain contaminated groundwater, and to manipulate the groundwater flow field. The adjustment of these two demands (energy vs containment) is complex but essential. The design of the groundwater system, coupling of wells, the management of pumps, sensors, as well as the in-house installations and other aspects had to be co-ordinated. By combining the design activities in one project team, a coherent design was made possible.

1.2 Technical solution

Change of concept

ARCADIS found the first part of the answer by a change of basic concept for the groundwater system. Instead of using cold and warm zones in the subsurface it was decided to use a so-called recirculation system, which uses a constant flow direction and extracts heat or cold from groundwater with a constant temperature (at the Eindhoven site 12-13 C). This conceptual change enables the merging of two worlds into robust synergy; using a circulation system for energy extraction, an effective approach for containment is possible, that also enables the stimulation of natural degradation. In practice, the recirculation system consists of an ingeniously designed system of extraction and infiltration wells. In figure 2 the basic principle is illustrated. The cluster of infiltration wells is surrounded by extraction wells, which capture the contaminated groundwater.

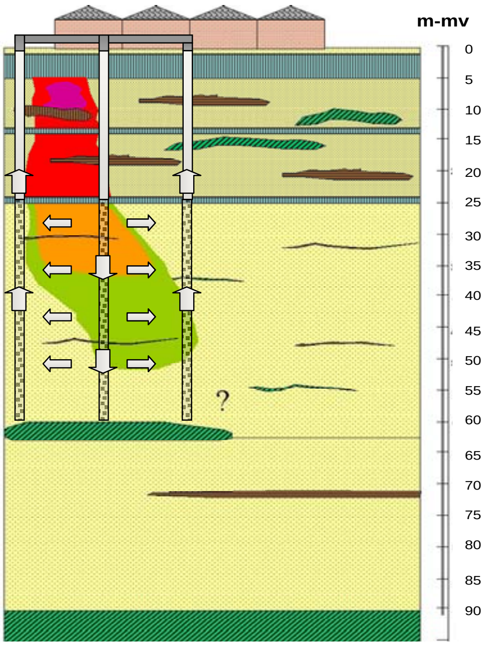

Figure 2: Basic principle of Sanergy

Stimulation of natural degradation

Natural degradation at the site is limited by the rate of the mixing of bacteria, nutrients and contaminants. Conceptually, the groundwater system can be compared with a washing machine put in to action. Laundry, water and detergent are mixed more efficiently. It will be a “biowashing machine”. If natural conditions are insufficient, or if there is a lack of nutrients, the set-up offers the opportunity to add the necessary substances. It is a contained system that can be compared with an in-situ system.

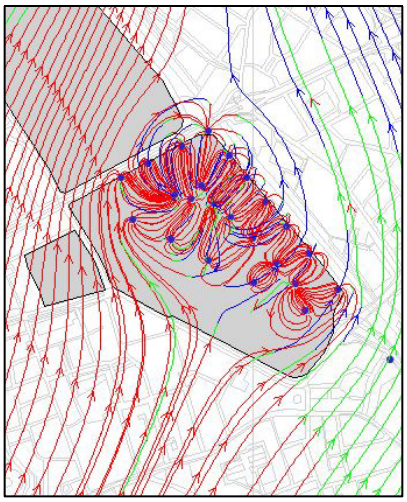

Figure 3: Influence on groundwater flow

From feasibility study to full scale system

The use of a groundwater system to combine both groundwater energy and remediation was not applied before. Therefore, it was necessary to check:

- the level of containment possible at the site with a neutral water balance (water out = water in);
- The development of soil and groundwater temperatures;
- The environmental impacts of the system.

The level of containment was optimized in an iteration process with flow path analyses. The final set up was calculated with a solute transport model. The contaminant flux leaving the site is reduced with a factor 4 (figure 3). In a strong flow field it could be possible that injected heat reaches the extraction wells whilst cold is still needed. In summer hot water is injected, in winter cold water. The effect of heat/cold circulation was modelled with a transport model. Heat or cold travels slower than groundwater. After a modelled period of 20 years, it showed that either heat or cold does not spread more than 30% of the distance between infiltration and extraction. An environmental impact study was executed for the groundwater permit.

1.3 Results

Reduction of CO2-emission, use of non renewable sources ànd cost

As the system was installed and initiated in the fall of 2009, result on energy saving and the response of the soil system are not yet available. It is calculated that the synergy leads to significant reductions of CO_2-emissions with about 3 Ktonnes (30-50%) and the use of non-renewable sources. The use of natural gas decreases for this 27 hectares site from 2.8 mln m^3 to less than 0.6 mln m^3. The use of electricity increases from 2.4 to 4.7 mln kWh as a result of the use of heat pumps. It is obvious that there is also a reduction of cost, estimated between 30-40%.

Until today it was not possible to use groundwater energy for the redevelopment of contaminated sites. The synergy of two worlds has taken away the barriers of the application resulting in a huge profit for our environment.

Reactions from Dutch regulatory agencies

Dutch Ministry of the Environment:
"In the Netherlands there are hundreds of areas similar with Strijp S, where perseverance and cooperation can cause that 1+1 will be more than 2. Areas with their specific character, dynamics and possibilities, areas that challenge developers, owners and buyers to think beyond the usual, innovate towards a sustainable environment. The government wants to transform the Netherlands into the cleanest and energy efficient countries in Europe. Groundwater energy is an essential element in this strategy. The redevelopment of Strijp S gives an extra cream topping: with sustainable energy towards an improvement of soil quality."

Municipality of Eindhoven:
"Strijp-S is crucial for the economical, social and spatial future of Eindhoven. It is a perfect example of an integral approach of possibilities and threats that groundwater represents. In the strategic agenda of our city 3 out of 12 focal points are directly related to the use of groundwater energy: a balanced sustainable economical development, quality of building and climat policy, and the program Strijp-S itself."

CASE 2:
GROUNDWATER MANAGEMENT UTRECHT

2.1 Introduction

Sustainable redevelopment

The inner city of Utrecht will be undergoing major changes over the next decade. The area around the central train station will be renovated, creating a new connection zone between Eastern and Western parts of the city. These developments will lead to many activities in the subsoil; groundwater extractions are needed for building excavations, Heat Cold Storages (HCS) are planned for sustainable cooling and heating of new offices and buildings and underground buildings and infrastructures are foreseen. Approximately 20 HCS systems will be implemented in the aquifer from 5-50 m-bgs, covering an area of roughly 6 square kilometers.

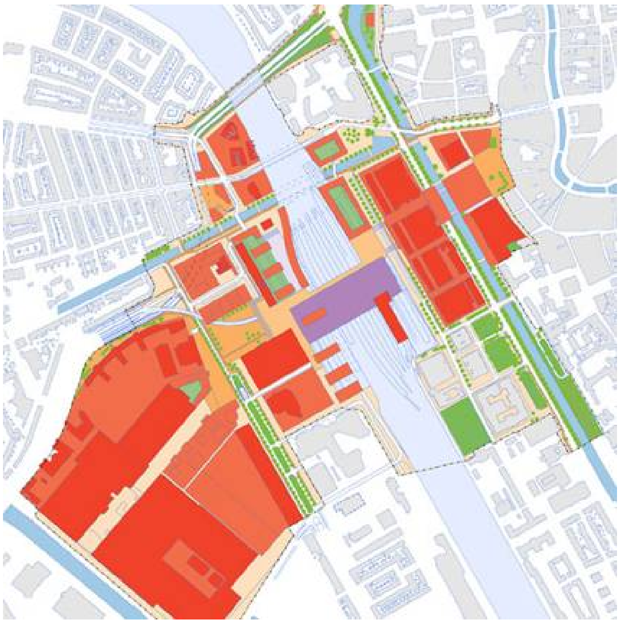

Figure 4: The centre of Utrecht in 2030

Utrecht is a historic city and has seen many industrial activities in the past. These activities have led to extensive groundwater contamination. Nearly 50 million m^3 groundwater in the aquifer where the HCS's are planned, is contaminated with chlorinated solvents and other compounds.

As was mentioned in the introduction, the movement of impacted groundwater as a result of initiatives in the subsurface is not allowed in the current Dutch legal framework. In situations such as the one in Utrecht, this condition prevents the functional use of groundwater and results in stagnation and frustration of the redevelopment processes.

Redevelopment provides the momentum

Although the contaminant situation is urgent under The Dutch Soil Protection Law, and remediation is necessary, traditional remediation is incredibly costly and time consuming. Without incentive and momentum, remediation was unlikely to happen. The redevelopment plans for the area and the (political and social) pressure have provided just the momentum to come to an efficient approach for how to deal with these bottlenecks. In 2007 a strategic plan was written for groundwater management in this area. In 2008 and 2009, this approach was detailed and established in a Remedial Action Plan. Currently that plan is going through the last permitting stages.

2.2 The approach, a groundwater management plan

From case based to a zoned approach

In the area around the Utrecht train station, approximately 30 different source zones and 20 plumes of contamination are known. But it is a large area, and there are also areas where no data is available, but contamination might be present. A case-based or site specific approach is not possible. Plumes intermingle making stand-alone remediation of separate plumes ineffective. The decision was made to define a system area (management zone), in which groundwater contaminants are allowed to move and mix, and where functional use of groundwater is allowed. The groundwater policy of the city of Utrecht is in line with the Dutch policy in this area, and is aimed at the improvement of groundwater quality, protection of clean areas and sustainable/functional use of groundwater. The shift from a case-based approach to this zoned approach is illustrated in figure 5.

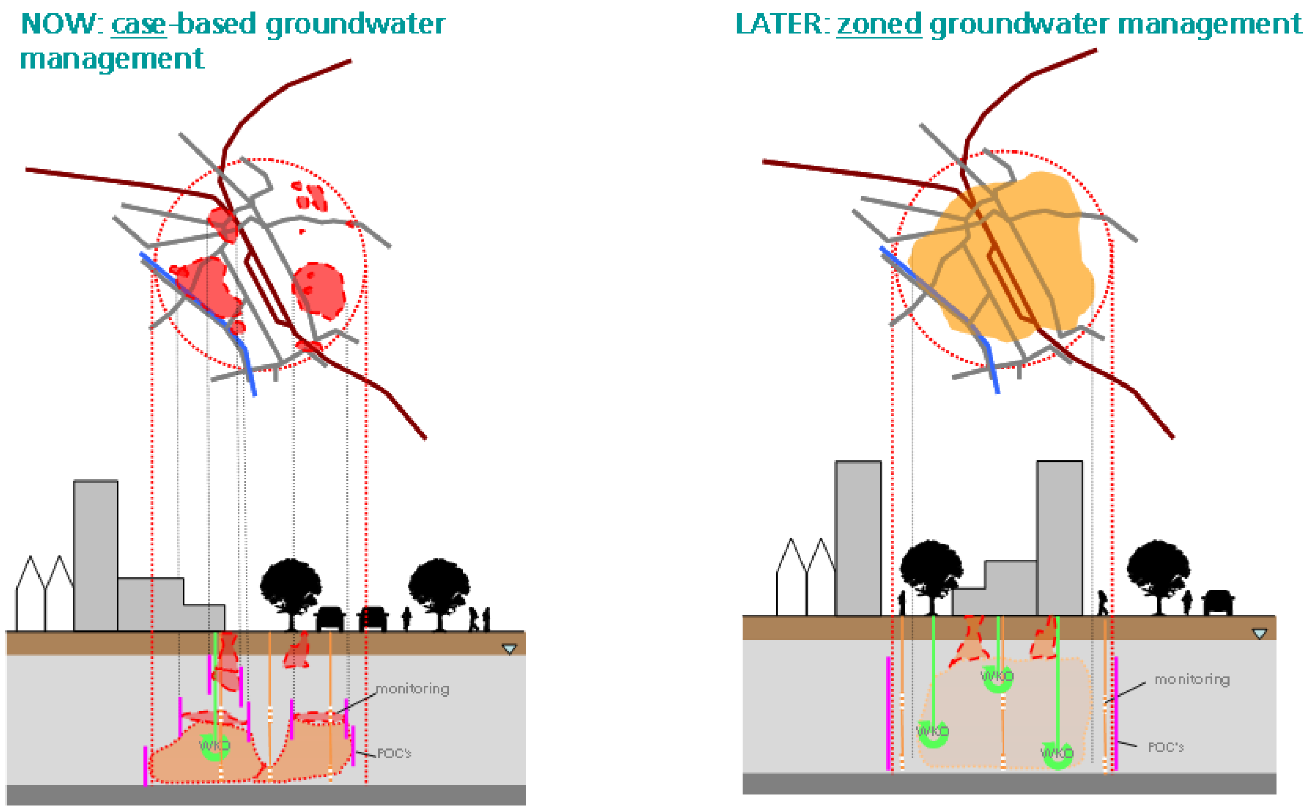

Figure 5:From case based to a zoned approach

In figure 5 it can be seen on the left hand that in a case based approach HCS (in Dutch WKO's) are not really possible without moving contaminants. Also there are many Plains of Compliance (POC's) of the plumes and these POC's interfere. In a zoned approach (right hand) that is only one POC, the circle surrounding the area. Sustainable use of the groundwater is made possible, as long as the surrounding, clean environment is protected against contaminants. They are not allowed to cross the system boundary (or POC).

Decoupling shallow impacts from deeper plumes
An important aspect of the chosen strategy is that the shallow and deeper impacts are treated separately, the zoned approach only applies to deeper impacts. The rationale behind this choice is that for the shallow impacts, the extent of the shallow impacts is relatively small, the relation between impacts and original source location are still evident and the risks of these impacts can be significant. This makes a case-based, location-specific approach viable. In the deeper groundwater, the connection between the original source and the mixed plumes is gone, the risks of the contaminants are completely different and the extent is much bigger.

The general idea of the groundwater management zone is to allow the functional use of groundwater, while allowing natural attenuation processes to keep the total extent of the impacts at a stable level, without creating risks. Incidentally, Utrecht already had experience with HCS's in contaminated groundwater, where it was found that although the extent of the plume increased, groundwater quality improved significantly. This started the idea that the HCS could potentially help the attenuation processes in the subsoil.

Groundwater and solute transport model
Utrecht decided to adopt the zoned groundwater management approach, and a Remedial Action Plan was written to create a formal framework for the activities in this area. Measurements on actual concentrations have created sufficient trust, but there was a need for more evidence. Extensive modelling was used to give weight to the claims in the Remedial Action Plan. In parallel, Utrecht started a research project into biodegradation processes in HCS-systems.
A sound conceptual model together with a robust model prediction showed that the objective of the approach can be achieved. As a result of groundwater pumping by the HCS's, groundwater will be mixed and natural degradation will be influenced. Approximately 10 million m^3 will be pumped yearly. An extensive groundwater and solute transport model (RT3D) was build in which all HCS wells (89), contaminant plumes (19) ánd contaminated sources (29) were incorporated. Degradation rates were estimated based on field data, and 4 scenarios with differing degradation rates were regarded. In figure 6 the modelling results are represented for vinylchloride in the layer between 15 and 30 m-bgs. Inside the area of influence of the HCS's the effect on the contaminants is evident.

2.3 Results

Groundwater modelling
The solute transport model gave basis to the goals of the groundwater policy of Utrecht:
- The outer contours of the contaminants shift marginally. The risk that contaminants will pass the Plains of Compliance is small (protection of clean areas).
- The use of groundwater for groundwater energy (HCS) is possible and pays a positive contribution to groundwater quality (sustainable use of groundwater).
- With conservative degradation constants the total amount of chlorinated solvents is expected to decrease from approximately 6000 kg to 4000 kg over a 30 year period (improvement of groundwater quality).
- Changing the half-life time for vinyl chloride from 10 to 20 years did not lead to noticeably different results.

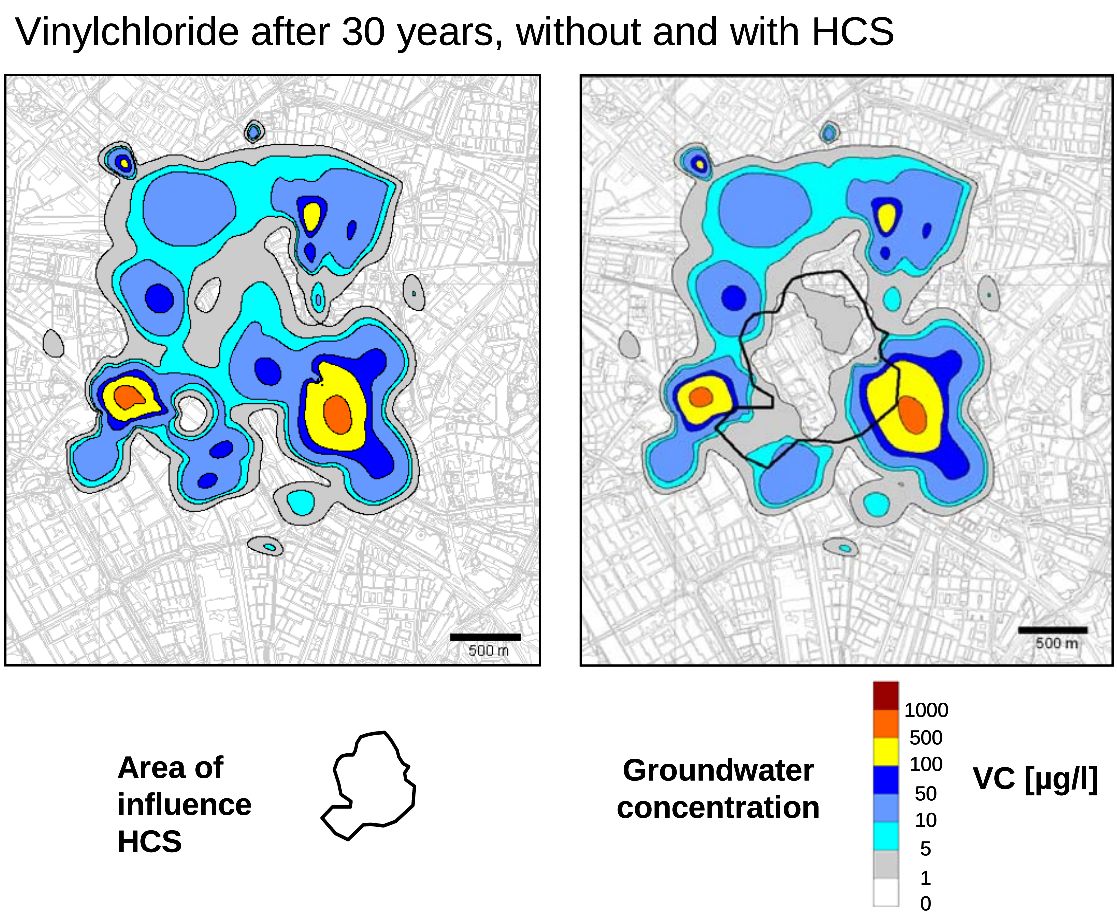

Figure 6: Modelling results Vinylchloride at a depth between 15 and 30 m-bs, without (left) and with HCS

Implementation

The concept that is outlined in the previous paragraphs will be implemented by installing a groundwater monitoring network (figure 7). This will be used to closely follow the development of groundwater quality and the spreading of contaminants. Decision schemes, action values and fall-back scenarios are part of the Remedial Action Plan.

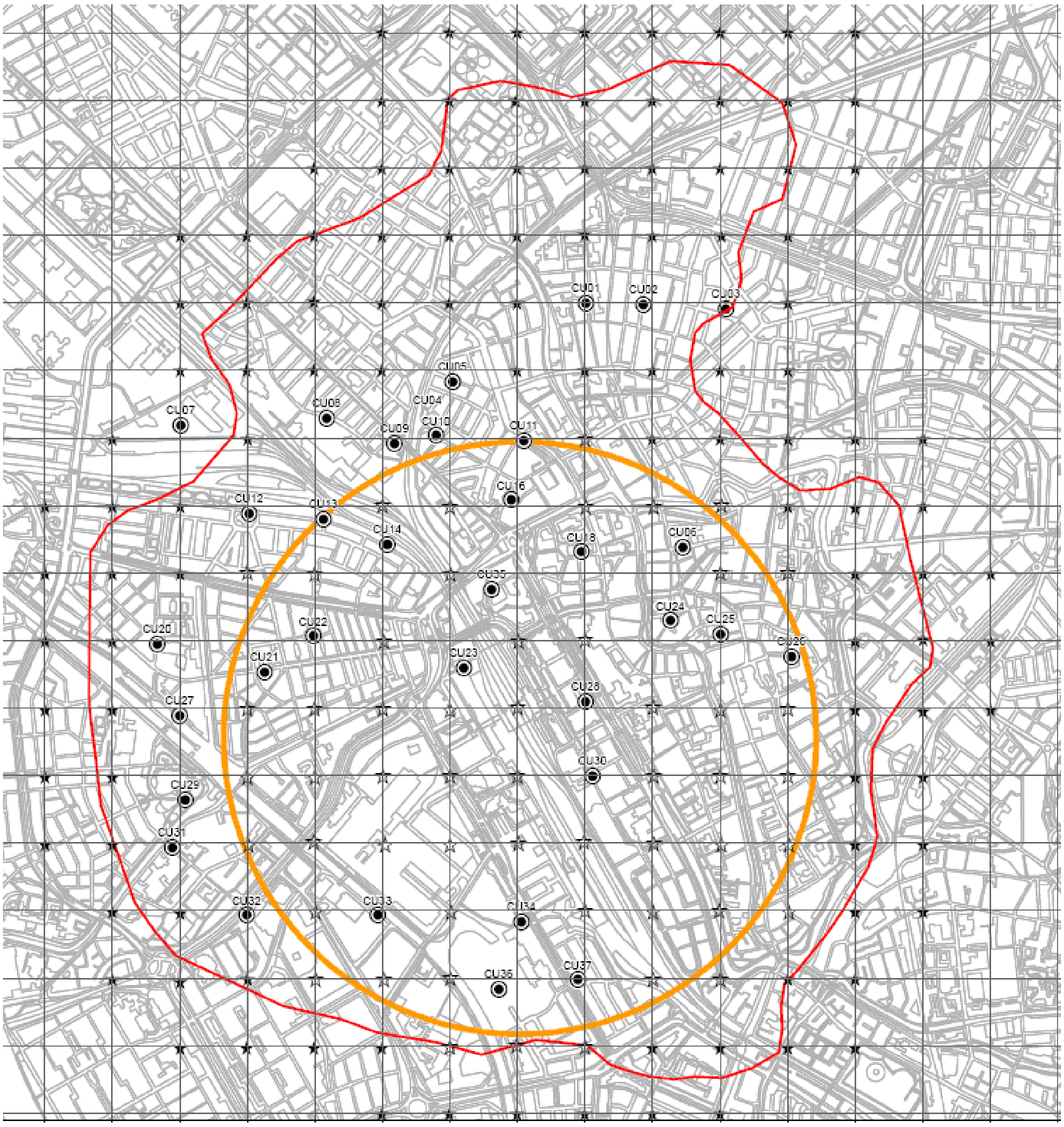

Figure 7: Monitoring network Groundwater management zone Utrecht

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