3 The hydrogeology of the Veluwe

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Location

The Veluwe area is an elevated region in the central part of the Netherlands, see Figure 3.1. The region is bordered by Veluwe lake in the northwest, the IJssel river in the east, the river Rhine in the south and Gelderse Valley in the west. Some larger towns border the most elevated parts of the area: Zwolle, Apeldoorn, Arnhem and Amersfoort. The area is dissected by some highways (A1, A12, A28, A30, A50), but does not contain any large streams or rivers. The most elevated point on the Veluwe is 'Signaal Imbosch' in the southeastern part of the region, with an elevation of about 110 m+MSL.

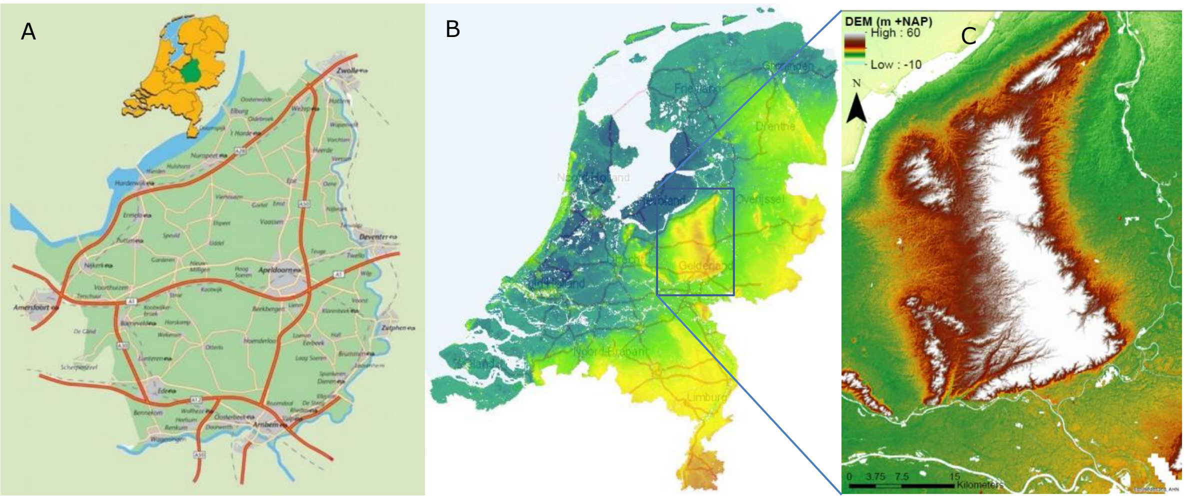

Figure 3.1 A) Veluwe area in the Netherlands (www.veluwsegeslachten.nl), B) topography Netherlands and C) topography Veluwe region (www.ahn.nl)

Geology

The Netherlands is part of a large depression (North Sea Basin) which is gradually sinking and being filled with Quaternary sediments, Figure 3.2B. This so called geosyncline is bordered by Cambro-Silurian rocks from Brabant Massif and Devonian rock in the Belgian Ardennes, see Figure 3.2A. At southeast the basin is bordered by the Rheinische Schiefergebirge (Eiffel and Sauerland). In the subsoil of the Netherlands a horst and graben structure with southeast-northwest oriented faults can be found. Pre-Quaternary rocks only surface in small areas, i.e. Mesozoic sands and clays in the eastern part of the country (close to Germany) and Mesozoic (Cretaceous) sands, clays and chalks in South-Limburg. In the southernmost part of the Netherlands Palaeozoic (Carboniferous and Devonian) highly consolidated sandstones, shales and limestones can be found.

In the central part of the Netherlands (near Utrecht) the thickness of the Quaternary deposits vary between 100 and 200 m. In the Early- and Middle-Pleistocene these fluviatile sediments have mainly been deposited by the rivers Rhine and Meuse. During Late-Tertiary the river Meuse flowed east, downstream of the Belgian Ardennes and joined the river Rhine in Germany. At the final stage of Tertiary, because of the continuous sinking of the North Sea Basin, the river Meuse could not reach the river Rhine anymore and started to follow an own path through the Netherlands. During Early- and Middle-Pleistocene these rivers had a parallel bed in southeast-northwest orientation. The river Rhine at that time followed a route which is now occupied by the river IJssel and the river Meuse followed a path which is now known as Gelderse Vallei. The alternating mainly braided and sometimes meandering flow system of both rivers at that time have resulted in a sequence of coarse sand and gravel layers and silt and clay layers in the subsoil of the area. The deposits of each river have their own characteristic lithology. The difference can still be traced through its gravel and mineral composition.

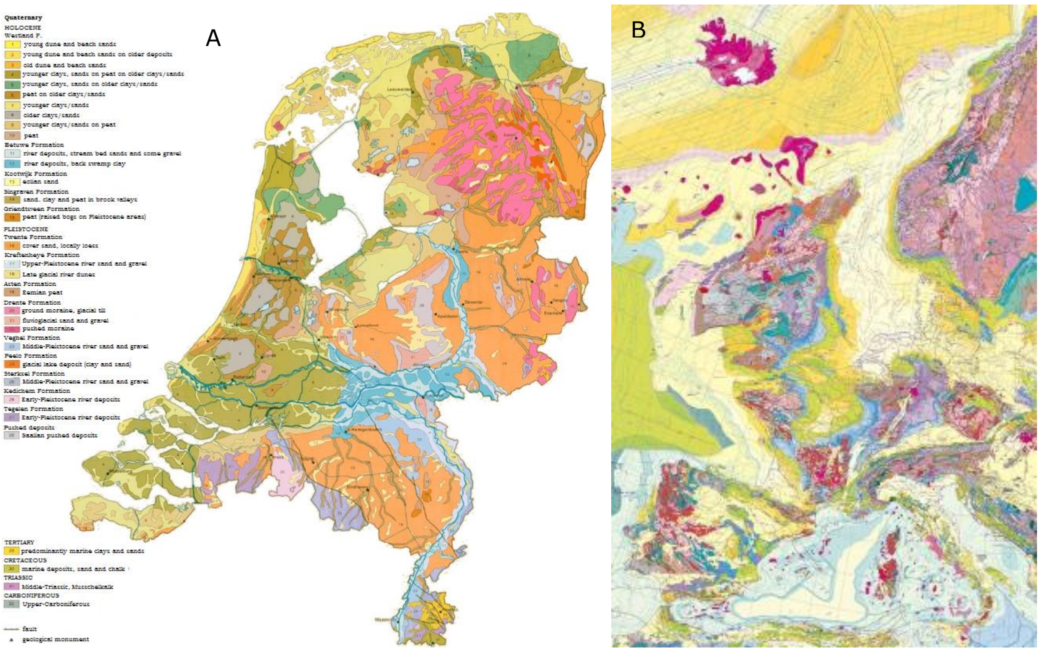

Figure 3.2 A) Geological map of the Netherlands (after NITG-TNO, 2004), and B) Geological map of Western Europe (IMGE 5000)

During Late-Pleistocene glacial periods were intermitted by interglacials (triggered by the Milankovitsch cycles). The first glaciation affecting the Netherlands was the Elsterian ice age (~450.000 years ago). The ice sheet just touched the Netherlands in its northern parts (Friesland and Groningen), the rest of the country experienced cold glacial tundra conditions. The next ice age, i.e. the Saalian ice age (~200.000 – 126.000 years ago), had a large influence on the Dutch landscape. An ice sheet entered the Netherlands from the north (Scandinavia). At least five expansions of this ice sheet can be traced in the Netherlands. Every time a series of pushed moraines or ice-pushed ridges were formed. During the third expansion the ice sheet reached its southernmost position along a line from Haarlem to Nijmegen (approximately 140.000 years ago). The ice front did not develop as a straight line, see Figure 3.3. In the northern part of the Netherlands there was a complete coverage by the ice, but more to the south the ice front followed the former river valleys of the Rhine and Meuse and its tributaries, e.g. the current Gelderse Vallei and IJssel Valley. The Ice mass in the valleys deepened the valleys up to ~50 m below sea level and pushed the valley flanks upwards, up to ~50-60 m+MSL and at some locations to >100 m+MSL. In this way the so-called ice pushed ridges developed in the area. In front of the ice sheet a wide east-west oriented melting water valley was formed by the Rhine, Meuse and many other rivers. All these rivers were forced to flow in western direction by the ice and had to find their way to the Atlantic Ocean via the Channel. Nowadays the Rhine and Meuse are still in this river bed in the central part of the Netherlands. Other relicts of the glaciation in the Netherlands are the glacial till layers, which developed as ground moraine below the ice sheet. Now, in the north of the country these poorly sorted till layers are still close to the surface, see the pink coloured areas on Figure 3.2A. These till layers cause soil drainage problems because of its low hydraulic conductivity. As a result an intense drainage network of brooks developed on the glacial till (Figure 3.4A). In Wageningen and surrounding area the glacial till can be found in the subsoil of the Gelderse Vallei (Figure 3.4B). Furthermore melt water or fluvioglacial sediments can be found in these glacially affected areas. In the valleys, e.g. the Gelderse Vallei, they occur at greater depth (glacial sand in Figure 3.4B), but at the Veluwe area they can be found at the surface. These poorly sorted coarse grained melt water deposits are called 'Sandr' when they are at the surface.

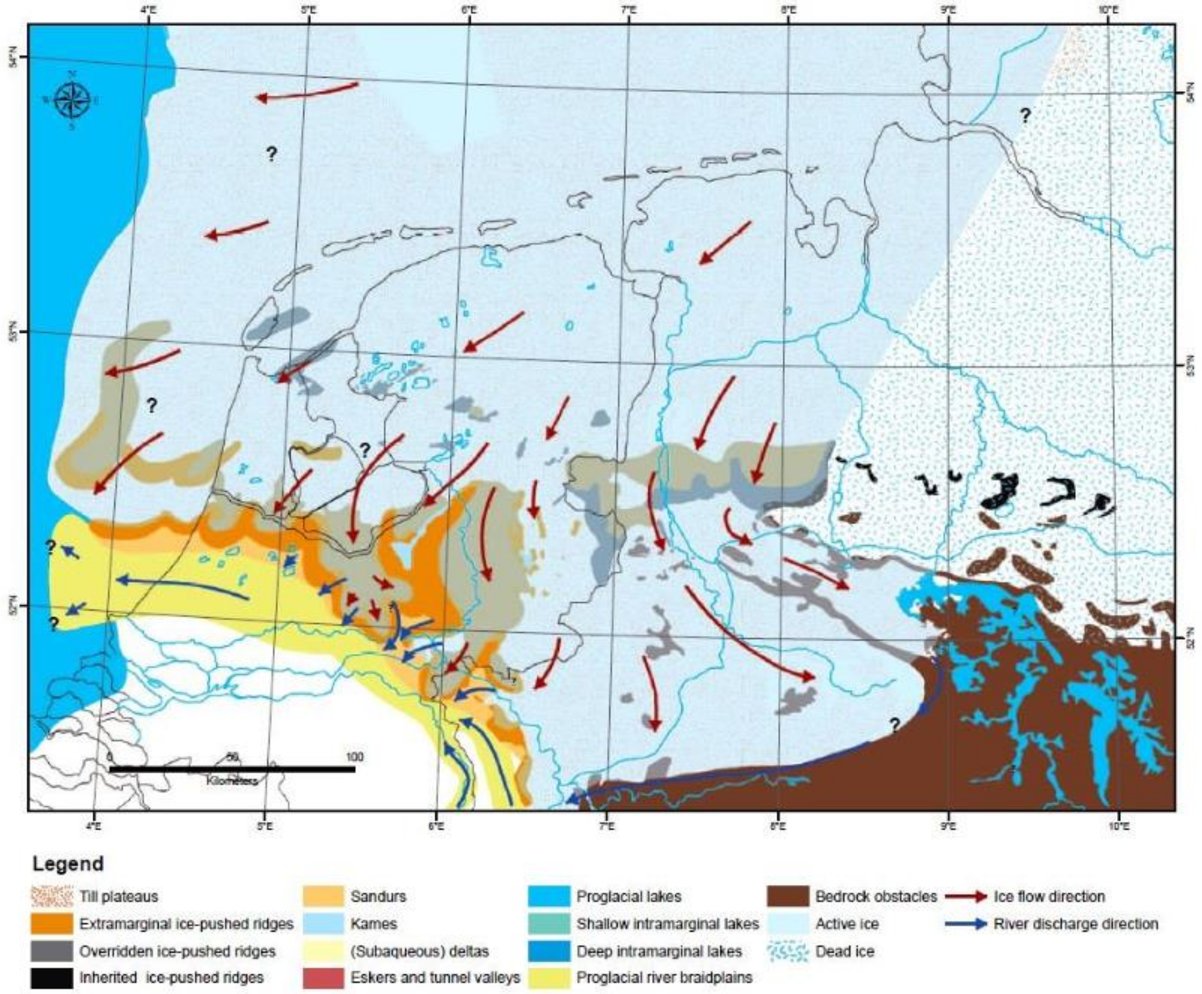

Figure 3.3 Morphology of the Netherlands during Saalian ice age, approximately 145.000 years ago

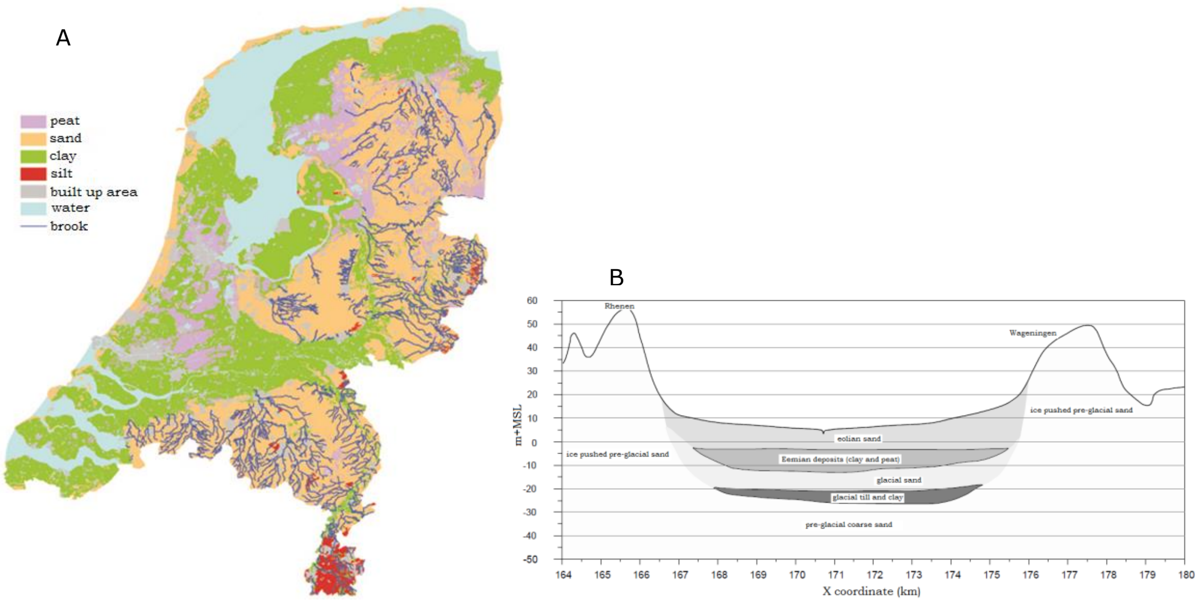

Figure 3.4 A) Brook valleys in the Netherlands (after Verdonschot, 2008), B) schematic cross section Gelderse Vallei

During the interglacial Eemian (126.000-116.000 years ago), sea level rose to up to 6 m higher than the present sea level. In some of the deep glacial valleys (northern part of Gelderse Vallei) marine clay was deposited.

During the most recent glaciation, the Weichselian ice age (115.000-10.000 years ago), the ice front did not reach the Netherlands. Periglacial conditions prevailed in the Netherlands. The permafrost prevented precipitation to infiltrate into the soil, which caused severe erosion on sloping land, such as the ice-pushed ridges. In this way pronounced valleys developed on the flanks of these ridges. These Pleistocene valleys have often an asymmetric cross section. After the glaciation period the permafrost disappeared and the deeply incised valleys, which had to transport meltwater during the glaciation, turned into so-called dry valleys. Nowadays they still can clearly be recognized in the field. In some of the meltwater valleys from Saalian time, e.g. the Betuwe, braided rivers deposited thick layers of coarse textured sediments.

During Weichselian ice age also aeolian sediments were deposited. Strong winds from the west blew sand and silt out of the shallow braided river beds and the dry North Sea basin. In a large parts of the Netherlands, this aeolian process caused that well sorted sediments covered the landscape which was almost free of vegetation at that time (polar desert). Usually the aeolian deposits have a sandy nature and are called cover sands (~200 µm). These sands occur at the surface in for instance the Gelderse Vallei and on parts of the Veluwe. Sometimes they have a low dune like topography. In sheltered locations, such as some of the southern slopes of the Veluwe, and farther to the south in the Netherlands, silts (2-50 µm) were deposited.

About 10.000 years B.P the next interglacial started, i.e. Holocene. This led to renewed vegetation cover and soil formation. The windblown sands were fixed to their location. In the Gelderse Vallei and on the Veluwe hardly any sediments have been deposited during Holocene. In these regions the Pleistocene sediments form the current surface layers, except from areas with Holocene brook sediments, peat and river clay.

In the floodplain (Betuwe) the braided river rivers, e.g. the Rhine and Meuse, changed to a meandering system, with more constant discharge and more or less fixed beds. Predominantly, loamy and clayey sediments were accumulated. The loamy sediments can be found in the natural levee along the river. More coarse sediments can be found in the actual river bedding and in the point bars. Layers of coarse sands also occur downstream of a dike burst. Until the time of the dikes were built to protect the land against flooding, the river changed its position every now and then. In the Betuwe this process has resulted in a number of wide meander belts with light textured sediments (natural levees). Former river can be covered by back swamps now (clay; < 2µm).

Recharge

Even though the Netherlands is considered to be a flat country, the relatively low ridges and hills still cause air masses to rise. When the air masses are forces to rise, they enter colder parts of the atmosphere. When air cools down the relative moisture content will increase. As a result, more precipitation can occur at these ridges and hills. Downwind of the ridges the air masses can go back to their original position in the atmosphere. It can warm up a bit again, so the relative moisture content decreases. This, in combination with the fact that the air mass lost quite some water through precipitation at the ridges and hills, causes a rain shadow downwind of the ridges. Figure 3.5A shows the long-year average precipitation in the Netherlands, period 1981-2010 (KNMI, 2011). The more elevated regions in the Netherlands are clearly visible with a maximum of 950-975 mm y-1, relative to an average of ~800 mm y^{-1} and the lowest value of 725-750 mm y^{-1}. Not only natural obstructions have an impact on the spatial distribution of precipitation. Also the larger cities (with their high buildings) have an impact on the distribution of precipitation (line Haarlem-Amsterdam and The Hague-Rotterdam). On the Veluwe, the highest average precipitation amount (also the highest amount in the Netherlands) is recorded near Hoenderlo (950-975 mm y^{-1}). Average precipitation on the Veluwe area is ~900-925 mm y^{-1}.

KNMI (2011) gives the reference evapotranspiration (ET_{ref}), according to the Makkink equation (Jacobs et al (2009); Equation 1)

$$ET_{ref} = C \cdot \frac{s}{s+y} \cdot \frac{K_{in}}{\lambda \cdot \rho} \qquad \text{Equation 1}$$

Where:

ET_{ref}	=	Makkink reference evapotranspiration (m d^{-1})
C	=	constant (0.65)
s	=	slope of the curve of saturation water vapour pressure (kPa $^oC^{-1}$)
y	=	psychrometric constant (kPa $^oC^{-1}$)
K_{in}	=	incoming shortwave radiation (J m^{-2} d^{-1})
λ	=	heat of vaporization (J kg^{-1})
P	=	bulk density of water (1000 kg m^{-3})

Figure 3.5B shows this Makkink ET_{ref}. In the southwest of the Netherlands ET_{ref} is slightly higher than in the northeast, 610-620 mm y^{-1} versus 550-560 mm y^{-1}. These differences are caused by the slightly higher annual temperatures and higher number of hours sunshine in the southeast of the Netherlands, compared to the northeast. In the Veluwe region, ET_{ref} is on average 560-570 mm y^{-1}.

The difference between precipitation and ET_{ref} gives the precipitation excess (P_{excess}). The spatial distribution of P_{excess} is strongly related to the spatial distribution of precipitation, see Figure 3.5C. The Veluwe area has the highest values of P_{excess}, ranging from 280 to 440 mm y^{-1}.

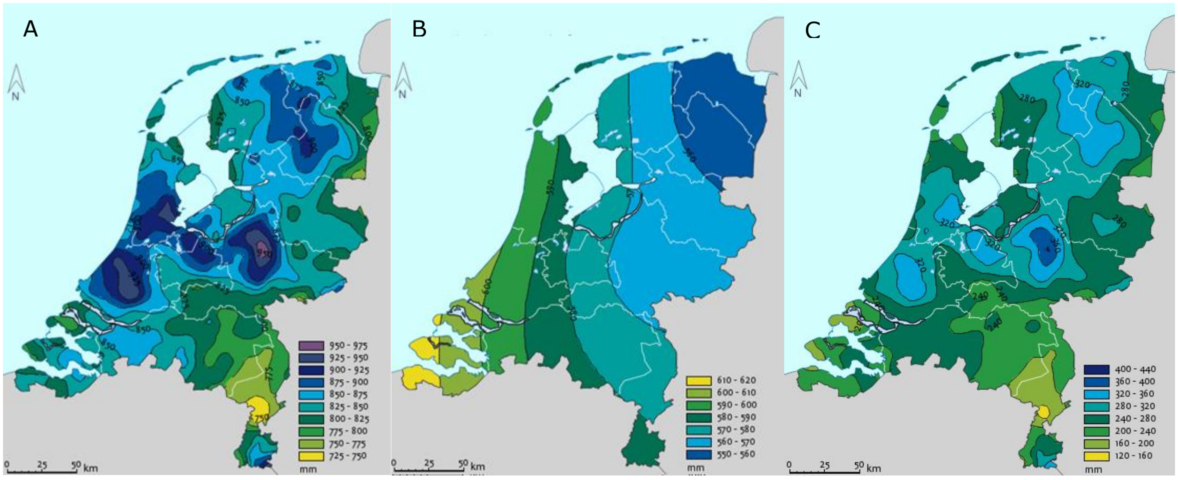

Figure 3.5 Long year averaged (1981-2010) A) precipitation, B) reference evapotranspiration, and C) precipitation excess, in mm y^{-1} (KNMI, 2011)

ET_{ref} can be converted to potential evapotranspiration (ET_{pot}) by incorporating land use. Different crops have a different water need. ET_{ref} is related to well-watered short grass. A crop factor (K_c) per land use (vegetation) can convert ET_{ref} to ET_{pot}. Douglas fir (*Pseudotsuga*) plantations on the Veluwe are known for their high crop factor and therefore high ET_{pot}. Drift sand spots are void of vegetation. They have a very low ET_{pot}, i.e. actually only some soil evaporation. The dark Douglas fir forest can reach an ET_{pot} of ~600 mm y^{-1}, where the drift sand can be as low as 200 mm y^{-1}. It is the expectation that converting 1 ha dark forest to drift sand will bring 4000 m^3 extra P_{excess}, or – with 10 km^2 converted to drift sand - a total of 4 10^6 m^3.

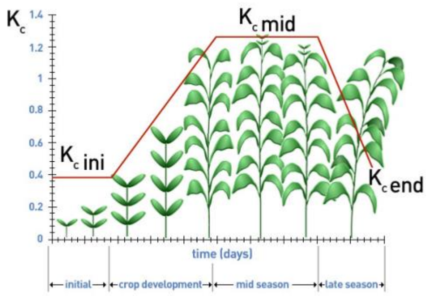

Figure 3.6 Crop factor (K_c) for maize during the growing season

ET_{pot} in its turn can be converted to the actual evapotranspiration (ET_{act}) by taking the soil moisture content in the root zone during the growing season into account. With sufficient water available ET_{act} is equal to ET_{pot}, during periods with water shortage, ET_{act} will be less than ET_{pot}. Wageningen Environmental Research installed lysimeters on the Veluwe to actually measure ET_{act}.

Hydrology

The actual P_{excess} will leave the root zone and will flow vertically through the unsaturated zone towards the groundwater level. The geological processes have resulted in an unconfined phreatic aquifer system with a high transmissivity in the ice pushed ridges and sandr in the Veluwe region. The transmissivity is assumed to be in the order of 4000 m^2 d^{-1} in the Veluwe aquifer.

The Lower-Rhine and IJssel have a water level ranging from 8 m+MSL near Arnhem to ~ 0.30 m+MSL near Zwolle (IJssel), see Figure 3.7. The small river Grift, which drains the Gelderse Vallei has a water level ranging from 4.5 m+MSL to 4.1 m+MSL.

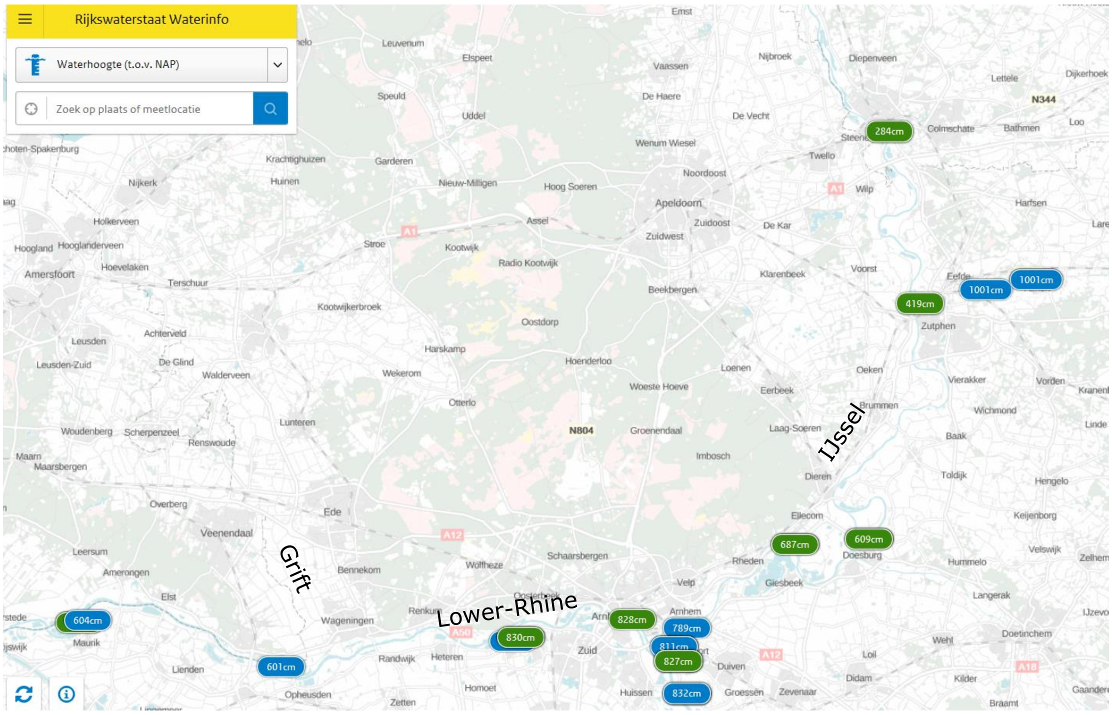

Figure 3.7 Surface water level in Lower-Rhine and IJssel (Rijkswaterstaat, 13 Feb 2017)

Figure 3.8 shows the groundwater level in a filter screen near Hoenderloo. Groundwater level fluctuates several meters (17 – 20.5 m+MSL in the measuring period 1969 – 2014). Since the early 90s the water level is around 18 m+MSL. This implies that the head difference between groundwater at Hoenderloo and river IJssel near Brummen is ~ 13 m. The difference between groundwater level at Hoenderloo and the books near Loenen – with an elevation of 11 m+MSL – is about 7 m. The gradient is therefore 0.65 m km^{-1} (13m/20 km) and 0.7 m km^{-1} (7 m/10 km), respectively.

Surface level at Hoenderloo is ranging from 55 to 95 m+MSL. With a groundwater level of ~ 18 M+MSL the unsaturated zone ranges from 37 to 77 m. This implies that the residence time of water particles in the unsaturated zone can be up to some decades. The vulnerability of these aquifer(s) is very high, because of the lack of semi-impermeable layers.

Figure 3.9 shows the isohypses (groundwater contour lines) and flow lines in the Veluwe region. It is clearly visible that the groundwater divide on the Veluwe is following a line from Arnhem to Zwolle via Hoenderloo. The gradient to the east is steeper than the gradient to the west. This is caused by the ice pushed clay layers in the eastern part of the Veluwe (Kedichem Formation), causing quite some hydraulic resistance. Part of the groundwater will emerge as seepage in the Gelderse Vallei, another part is even reaching the low part of the Netherlands, west of the Utrechtse Heuvelrug.

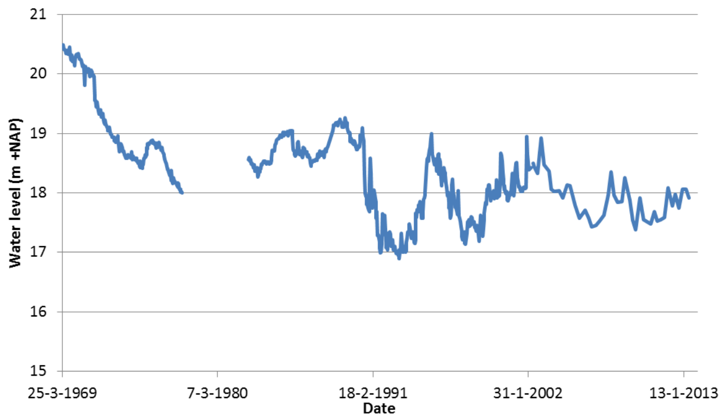

Figure 3.8 Groundwater level near Hoenderloo, period 1969 – 2014

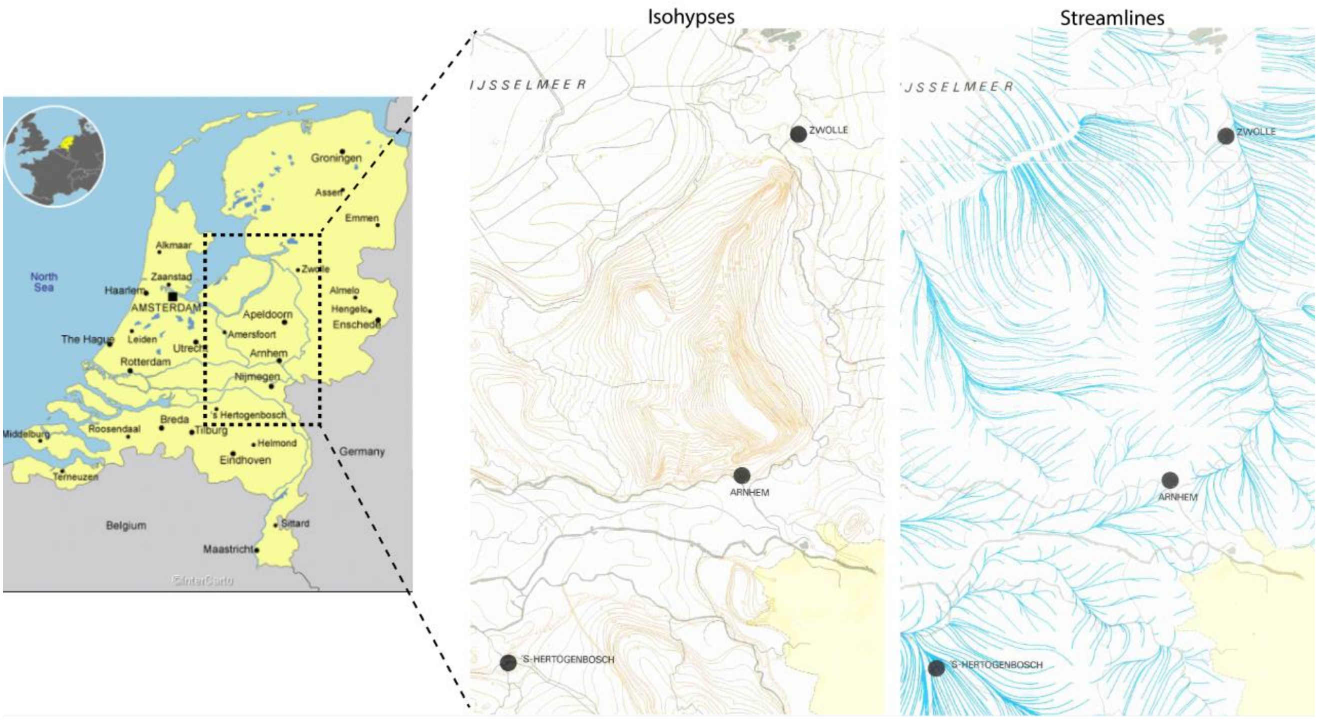

Figure 3.9 Isohypses (groundwater contour lines) and streamlines in the Veluwe region

At the interface between the more elevated regions (Veluwe) en the lower and flatter regions (i.e. IJssel floodplain) seepage occurs and brooks developed. At numerous locations the brook was extended towards the Veluwe and extra open drains were dug: the bowls (Sprengen). These bowls – mostly dug during the middle ages - acted as drain and therefore provided a relatively constant water flow. This water of very good quality was often used for small scale industrial activities, such as paper factories. Not only the water was used, often a water mill was built too, to produce some electricity.

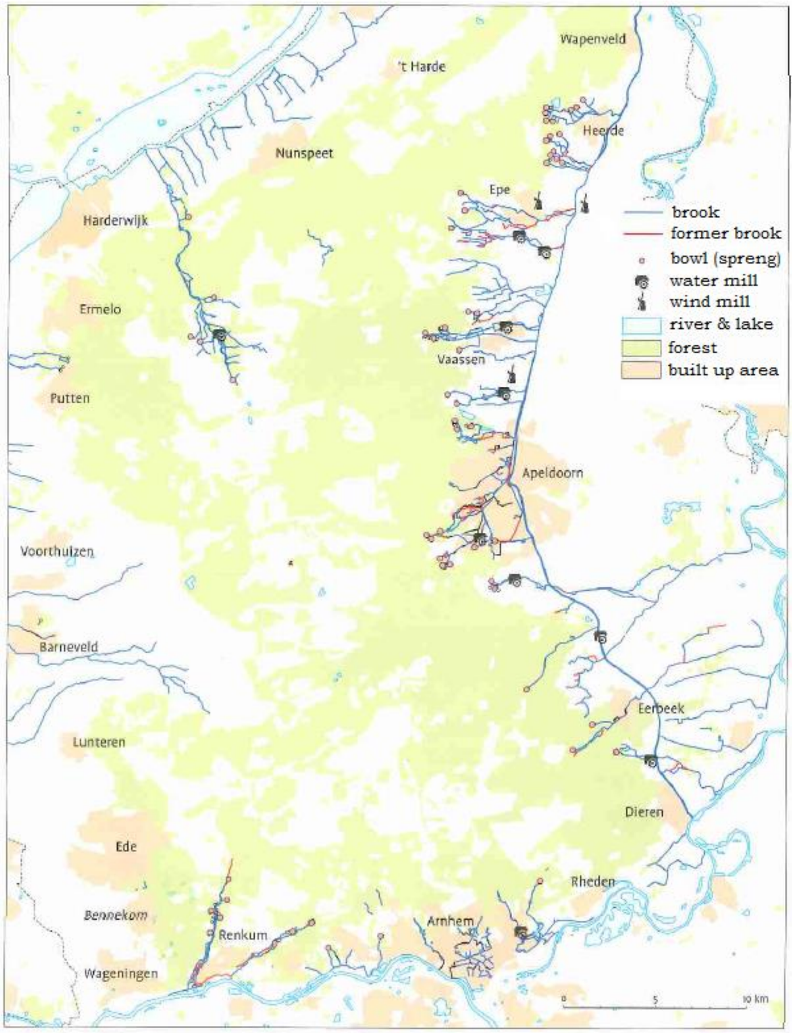

Figure 3.10 Bowl (spreng) brooks surrounding the Veluwe area (Noordhoff atlas producties, 2010)

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5 The hydrogeology of the valley of the Renkum brook

Roel Dijksma (Wageningen University)

Location

The Renkum brook (Molenbeek) and Heelsum brook are relatively small brooks in the so-call Renkum sandr area. The have north-south and northeast-southwest orientation and discharge into the Lower-Rhine. Both brooks have their headwaters (small springs) close to the Arnhem-Utrecht railway. See Figure 5.1 for their location and orientation.

In 2000, first plans were presented to recreate the Renkum brook towards an ecological corridor (Renkumse Poort). Over the years the dissection by roads, industry and villages turned the brook valley into a scattered landscape. A major challenge was to move the industrial activity from 'De Beukenlaan', west of Renkum to other locations and to transform this industrial area to a new segment of the ecological corridor.

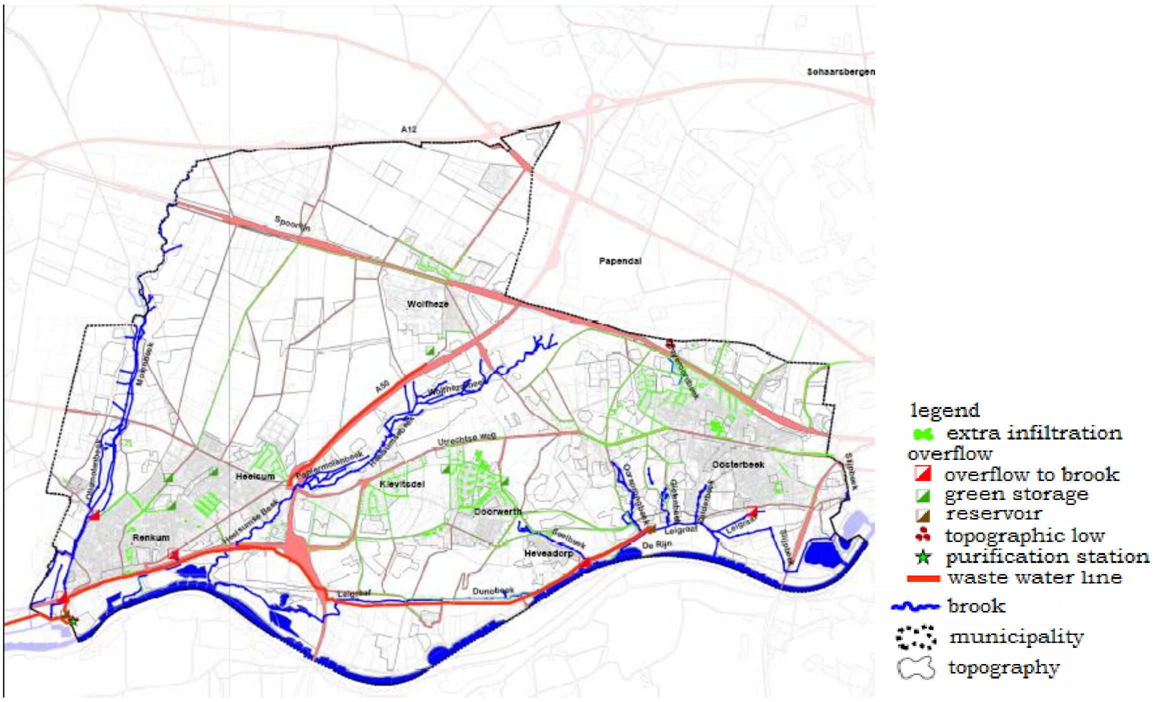

Figure 5.1 Renkum brook (Molenbeek) and Heelsum brook (after Royal Haskoning, 2007)

Figure 5.2 A) Land use in Renkum municipality and B) satellite image (adapted from google maps)

Figure 5.3 shows the ecological corridors surrounding the Veluwe area with corridor ‘De Renkumse Poort’ in the southwest of the Veluwe (Province of Gelderland, 2006). These corridors enable flora and fauna to migrate between the Veluwe and surrounding ecologically valuable regions.

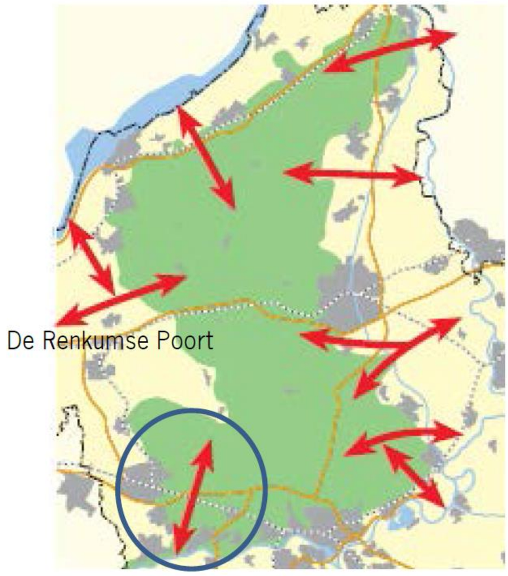

Figure 5.3 Ecological corridors surrounding the Veluwe. The so-called Renkumse Poort is indicated with a blue circle (source: Province of Gelderland, 2006)

Geology

The geological history of the Renkum brook is strongly linked to the Veluwe region. Figure 5.4 shows the geological map of this Veluwe region. The Renkum brook and Heelsum brook are indicated in light blue.

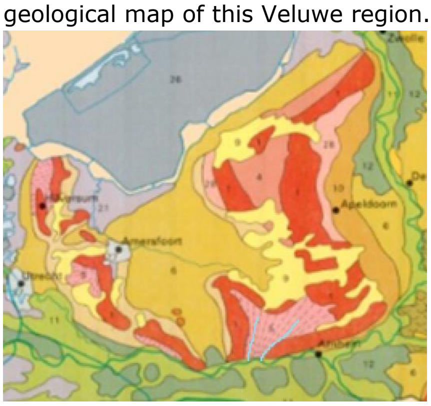

Figure 5.4 Geology Veluwe region

During Saalian ice age (see chapter 3) the glaciers created deep valleys and high ice pushed ridges. A large glacier tongue filled the Gelderse Vallei, with and east extension towards Otterlo. Another large glacier tongue followed what was the Rhine valley at that time, with an turn towards west near Dieren. This created an unglaciated area in between all moraines. Melting water from the glaciers flowed over the moraines, carrying large quantities of sediment. The course sediments were deposited in the area, the finer sediments were washed towards the Rhine. Because of this process the area is called outwash plain, or sandr area. In Figure 5.5 a west-east (A-A’) and south-north (B-B’) cross section is shown of this sandr area. The grey coloured formations (dtc) are the ice pushed moraines, the yellow coloured formations (drz1, drz2, drz3, urz3, urz5 (Drenthe F. sand and Urk F. sand)) are course sands and gravels in the outwash plain. At a depth of -20m+MSL the first pre-glacial clay layer can be found (wak1 (Waalre F. clay)). The yellow coloured underlying formations (pzwaz5, pzwaz7 (Peize-Waalre F. sand)) is considered to be an aquifer with its course river sands. The blue coloured formation (msc, Maassluis F.)) consists of Early Pleistocene marine clay. This formation is considered to be impermeable so is considered to be the hydrological base in the region.

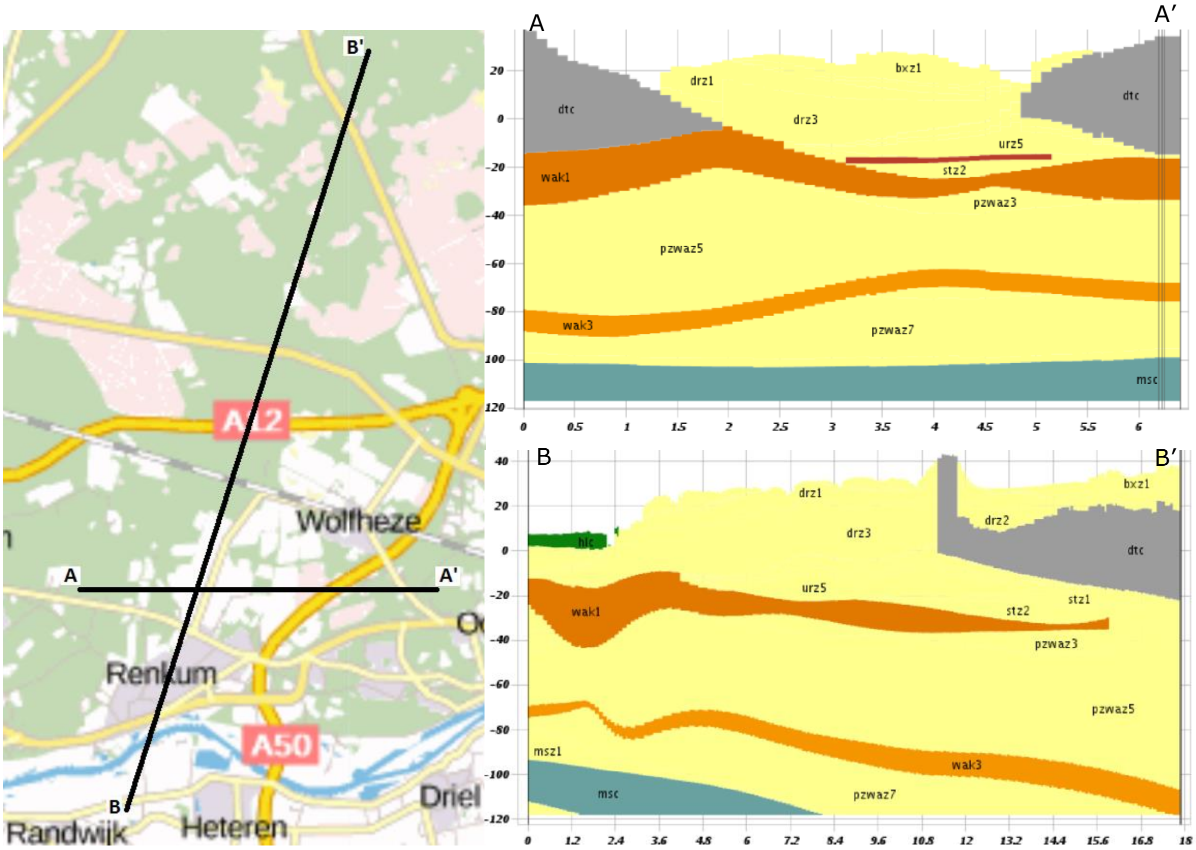

Figure 5.5 Geological cross section A-A′ and B-B′ and their position (source: www.dinoloket.nl)

Hydrology

All sandy formations can considered to be aquifers. The ice-pushed ridges (dtc in Figure 5.5) consist of poorly sorted sands. The sands belonged to the pre-glacial river sands. In the Doorwerth ridge (east in Figure 5.5) also a sequence of clay layers can be found. The permafrost in front of the glacier tongue reached up to the Waalre F. clay and was pushed aside as plates of sand and clay. The sequence of clay layers impedes groundwater flow in this ice-pushed ridge. More to the west, the permafrost did not touch the Waalre F. clay. Therefore the Wageningen-Ede ridge does not contain any clay and can be considered as a phreatic aquifer. The sands in the sandr area (Drenthe F. and Urk F.) are the outwash equivalent of the sediments in the ice-pushed ridges and have therefore an even higher hydraulic conductivity. This makes this sand layer also a highly conductive phreatic aquifer. The Waalre F. clay (wak1 and wak3) is acting as a resistant layer (aquitard). The pre-glacial Peize-Waalre F. (pzwa3, pzwa5, pzwa7) consist of poorly sorted course grained river sands and act as aquifers. Maassluis F. (msc) clay is the hydrological base in the area.

Figure 5.6A shows the isohypses (groundwater contour lines) in the Veluwe region and sandr area. Water infiltrating on the west flanks of the Veluwe can flow towards the west (Gelderse Vallei). Part of it follows a route in the direction of the sandr area, where most of the water flows through the aquifer system towards the Lower-Rhine. Part of the water is emerging in the (artificial) springs and as seepage in the Renkum brook and Heelsum brook.

Considerable amounts of water are abstracted from the aquifers in the sandr area and direct surroundings. This water is used for industrial purposes and for drinking water supply. For locations, see Figure 5.6B. Enka, a company producing fibres, started abstracting 4 10^6 m^3 y^{-1} water in the region in 1928. In a later stage this abstraction was reduced to ~ 3 10^6 m^3 y^{-1}. The company stopped its activity completely in 2003, see Figure 5.7. Parenco abstracted considerable amounts of groundwater during the 1980's and 1990's for its paper production. Nowadays predominantly Rhine water is used for the paper production. Some major groundwater abstractions for drinking water supply are located relatively close to Renkum brook, i.e. Wageningse Berg, La Cabine, Edesche Bos and Fikkerdries. Table 5.1 gives the abstracted amounts for these four pumping stations.

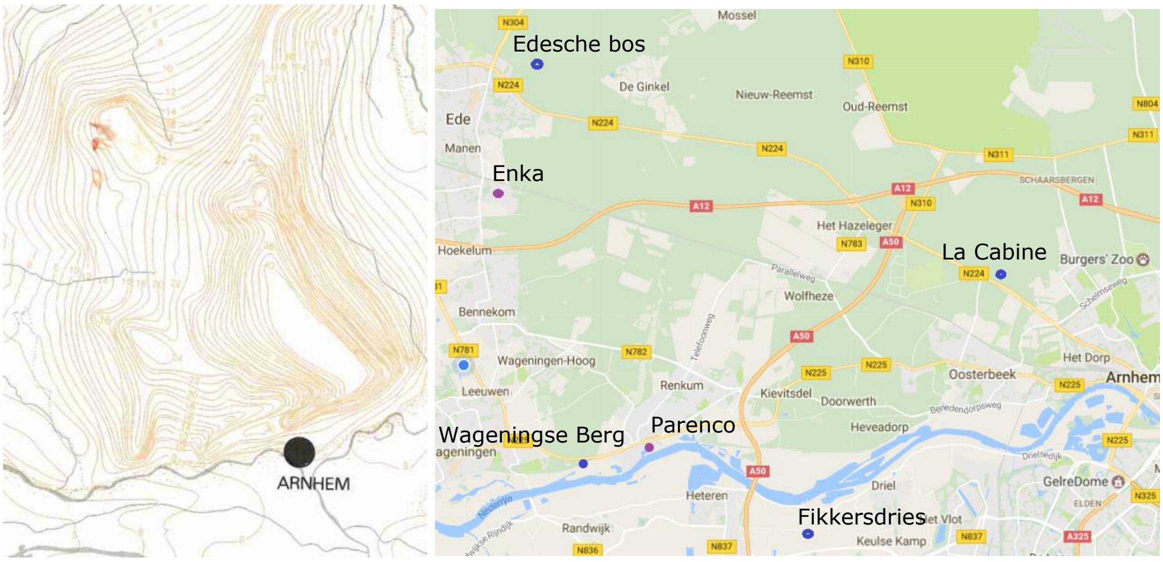

Figure 5.6 A) Isohypses (groundwater contour lines) in the Veluwe region and sandr area, and B) location drinking water pumping stations and large industrial abstractions

Table 5.1 Water abstractions near Renkum brook

Abstraction (2017)	Abstraction (10^6 m^3 y^{-1})	Start abstraction
Wageningse Berg	3.6	1898
La Cabine	10	1909
Edesche Bos	3.5	?
Fikkersdries	24	1975

Because of many water abstractions in the area the groundwater level has been dropping for decades (for drinking water supply (60% of the abstraction) and for industrial use (Parenco, Enka; 40% of the total abstraction). At some upstream locations the water level dropped more than 2 m. Since Parenco reduced its abstraction and Enka stopped its activity completely, some groundwater level recovery can be observed. Also the brook discharge has increased since then.

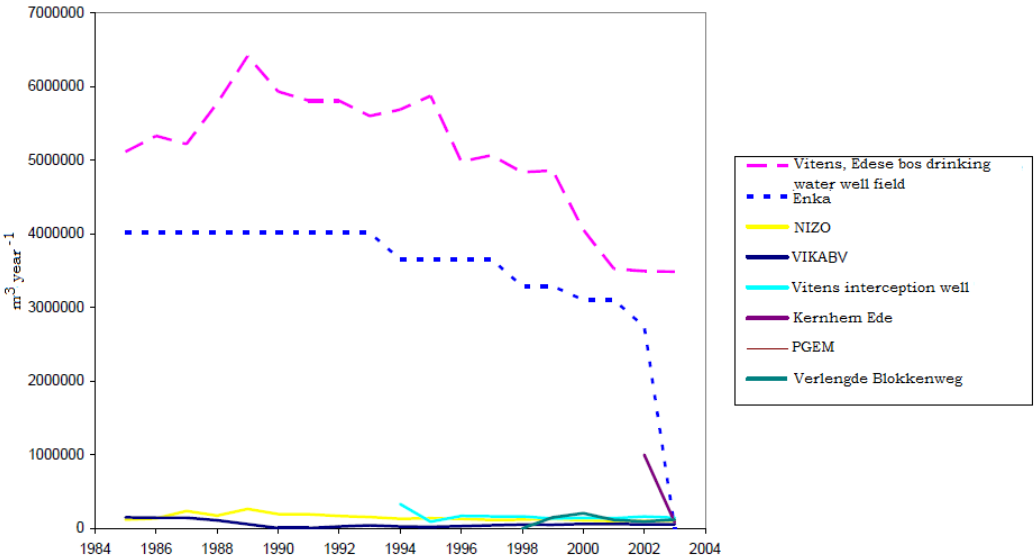

Figure 5.7 Water abstractions in the region Ede and surroundings

History

The first water mills date back to the 15th century. At the end of the 16th century the first water mills for paper production were constructed. Most of the brooks and bowls (sprengen) at the South Veluwe region are man-made or manipulated by men in the past (Water board Vallei & Eem; 2003). Already in the 17th century the digging started, in order to get more water in the stream and to feed the water mills. At some stage there were already even some 25 water mills in the Renkum and Heelsum brook. Therefore these activities can be seen as early industrial areas and industrially utilized streams.

Next to the original streams in their stream beds, parallel artificial streams were created ('sprengenbeken'). These streams have a minimal hydraulic gradient. By creating these artificial streams a head difference was created with the original steam. Small water mills used this head difference for some electricity production. The paper industry used to have workers maintaining the artificial streams. Otherwise, because of the minimal gradient, the stream would get clogged easily. The last brook maintenance by Van Gelder Papier was stopped in 1963.

Water from the brooks in the sandr area was used as process water up to 1954 by Schut Paper factory, and up to 1963 by 'Van Gelder papier'. Since then the paper industry used groundwater abstractions. The industry did not need the brooks and stopped the maintenance of all streams. In 1976 all brooks and their maintenance was brought to the National Forestry Service ('Staatsbosbeheer').

In 2000, it was at first the intention to renew the industrial area 'De Beukenlaan' in Renkum. At that time the first plans were made to move all the industry from the Renkum brook valley. This plan was put into action in 2007 and finished in 2013. Nowadays there is no economic activity in the area anymore. Ecological values prevail.

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