Nitrate-rich springs: influence of groundwater on surface water quality Executive summary

Introduction

This research aimed to gain scientifically founded insights into how the quality and quantity of phreatic (upper) groundwater can influence the quality of surface water, both at the level of specific areas, the catchment areas of MAP monitoring sites, and at a larger more regional scale. This research focuses both on the detailed mapping of nitrate-rich groundwater issues, where in a number of cases the feeding of surface water by nitrate-rich or nitrate-poor groundwater is studied in detail, and on the insights that follow for larger areas. This allows for a better assessment of nutrient losses and possible adjustment of policy measures after evaluation.

Ten cases were investigated located in the Sand region, the Sandy loam region and the Campines region (see Figure 1). Moreover, some of the catchments in the Sand Loam Region had predominantly loam as soil texture. Most of the cases were runoff zones from MAP surface water monitoring sites with exceedances of the 50 mg/l nitrate standard. Also, most of the cases were located in hill areas.

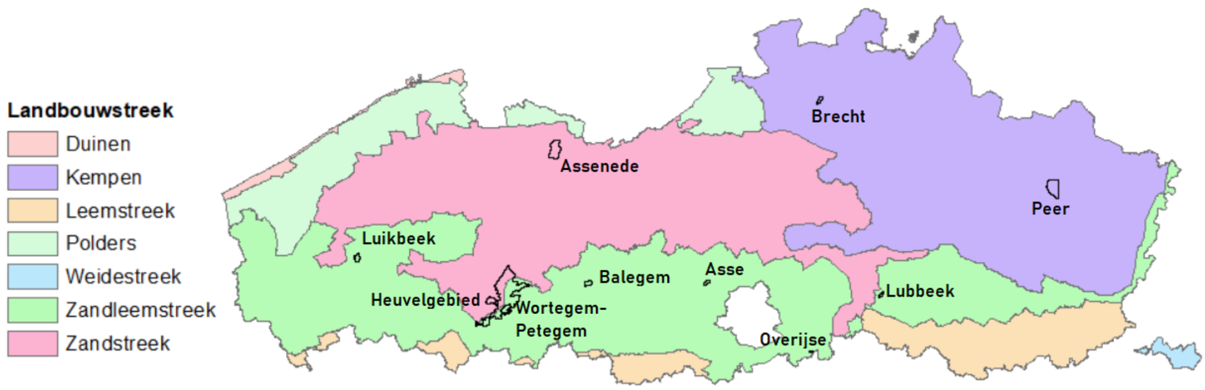

Fig 1 : Situating the 10 catchments that served as test cases.

During the study, data was collected in the field and models were used and developed that can be used for further calculations.

Groundwater is fed by rainwater that percolates through the soil. Nitrates are formed by mineralization of organic matter or are derived from fertilizers. Due to their negative charge (NO_3^-) they dissolve in soil water and are washed out to groundwater, especially in winter. The first part of this study therefore simulated the emergence of the nitrate problem in the unsaturated zone (soil above groundwater). Because of the sometimes long travel times of groundwater, simulations were performed over a 50-year period (1968-2017). Each catchment was divided into a grid with cells of 50 x 50 m. For each grid cell, the model EU-rotate_N was used to simulate the main N processes in the soil and in the crop on a daily basis. Daily weather data were obtained from the RMI. Figures for N deposition were obtained from VMM. The soil was characterized based on soil texture and SOM content and other parameters were derived using pedotransfer functions. Annual data were collected on fertilization and cultivation. The cropping history of each plot is known from 1997 onwards. For the period before 1997, the crops are randomly distributed on the grid, taking into account the statistical data at the level of the municipality (from 1980) and the agricultural region (before 1980). For fertilization, it was assumed from 2007 that the texture and crop-specific fertilization standards were fully completed. In the period before 1996, it was assumed that manure production was based on animal numbers at the level of the municipality (from 1980) and the agricultural region (before 1980). Thereby, the manure was distributed among the crops according to a cultivation factor related to N uptake. A transition period was provided (1996-2006) in which a linear decrease (export of manure) or increase (import of manure) in the difference between manure production and the fertilization standard was assumed.

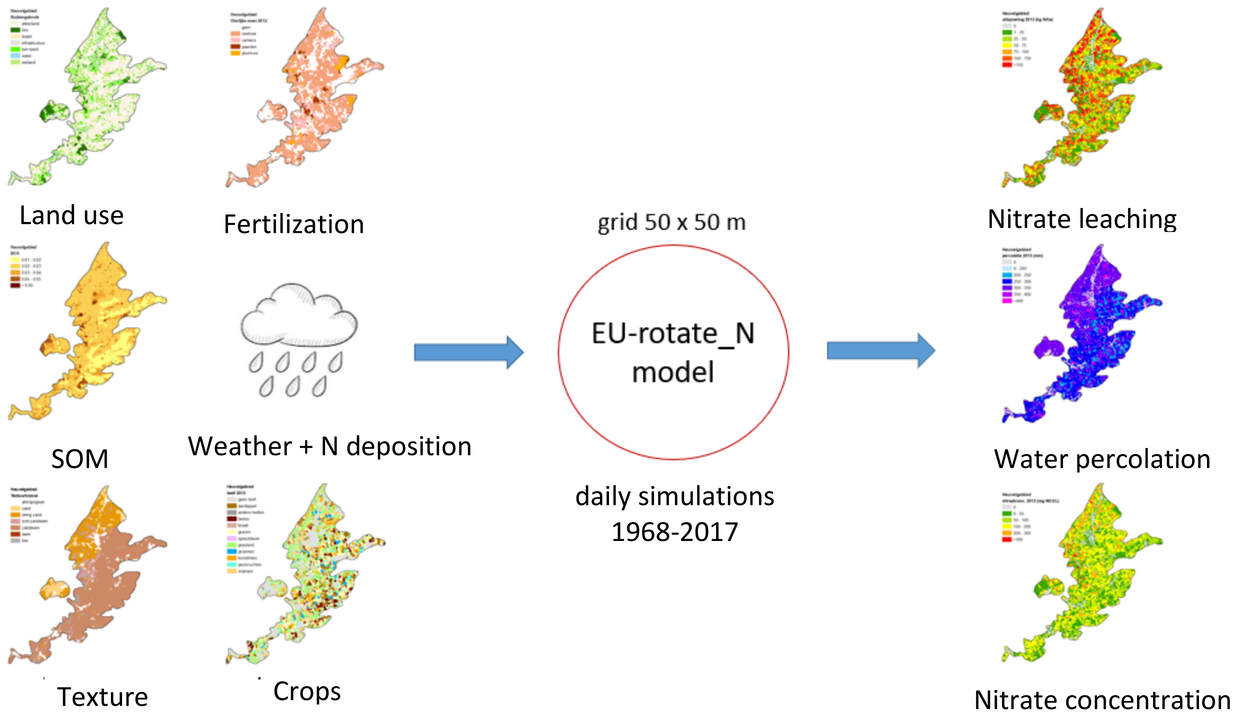

Fig 2 : Overview of the most important input and output for the simulations in the unsaturated zone.

Based on land use, the EU-rotate_N model was then used to simulate, per grid cell, cropland (rotation), pasture (permanent grassland), permanent fallow land, forest, and gardens or parks. No leaching was assumed for paved surfaces or water surfaces. Daily nitrate leaching and water percolation at a depth of 90 cm were reduced to annual values to serve as inputs to the groundwater model. For catchments with deeper groundwater tables, the travel time of nitrate flux to the groundwater table was calculated using the Hydrus-1D model. Validations using nitrate residue measurements showed that the model generally generates reliable results at the catchment level.

From the nitrate concentrations in the soil percolate of all plots within the catchment of a MAP monitoring point, the areal average is calculated which evolves as a function of time, year by year. This time series serves as input for a saturated zone model that calculates the possible nitrate transport through the groundwater to the watercourses. This is because the water measured at a MAP monitoring point is a mix of all groundwater that flows into the stream upstream of the MAP monitoring point. The saturated zone model classifies groundwater inflow according to three different supply routes :

Shallow groundwater drained by drains : this groundwater is captured just below the water table and is rapidly transported to the watercourse. This upper groundwater corresponds best to the soil leachate in terms of composition.

Shallow groundwater that is not captured by drains can flow to the stream in the upper part of the groundwater reservoir. In this part of the subsurface, there is no reactive material such as organic matter and/or pyrite and nitrate can spread unhindered. This layer forms the oxidation zone. The travel times of the groundwater can increase depending on the thickness of the oxidation zone and the distance to the watercourse that must be bridged. These travel times can be several years or even decades. The groundwater in this layer consists of a mixture of different ages, from young to old, but with the proportion decreasing as the age increases. The model takes this into account by applying an exponential distribution model for the groundwater ages.

Deeper groundwater flowing through the reduction zone : nitrate reduction can occur in the deeper part of the groundwater reservoir because of the presence of reactive material in the sediments, such as organic matter and/or pyrite (iron sulphide). This reduction process will remove almost all the nitrate from this part of the groundwater. The travel time and age of this deeper groundwater can be large but does not play a role at all because there is no nitrate in it anymore.

The division into the three inflows is done with the help of partition coefficients. Seasonal variations are simulated by using partition coefficients that can be defined monthly. Annual soil leachate and nitrate concentrations are obtained from the unsaturated zone model. The model then gives the nitrate concentration at the MAP monitoring point as a function of time.

Main results and observations per testsite

The 10 test sites were examined in detail and a report was prepared for each site which discusses the methodology and results in detail.

Important parameters in the analysis of the test sites include: the simulated annual nitrate and water flux from the unsaturated zone, the delineation of the catchment, the seasonal dynamics of the nitrate concentrations in the MAP monitoring point, the fraction of the water in the MAP monitoring point that comes from drainage, the fraction in the MAP monitoring point of the groundwater that comes from the oxidized zone, the median travel time of groundwater and the importance of runoff.

The following is a listing of the main results and observations for each test site:

1. Luikbeek (Staden)

The average simulated annual nitrate concentration in the soil leachate is 786 mg/l nitrate for the period 1968-2017 and is very high because of the extremely high historical fertilization pressure. With full implementation of the fertilization standards, a high average concentration of 282 mg/l nitrate was still simulated for the period 2007-2017, mainly due to the large share of agricultural use within the basin, with two-thirds of the agricultural area consisting of nitrate-sensitive crops (potatoes and vegetables).

In the Luikbeek site, a significant fraction of infiltrating water is drained by drains. The water that is not captured by drains ends up mainly in the reduction zone, so the deeper groundwater contains little nitrate. The main supply of nitrate to the MAP monitoring point comes from the drains, which therefore results in a very strong seasonality with peak values in winter and sudden increases and decreases when the drains start working or stop.

2. <u>Wortegem-Petegem</u>

The average simulated annual nitrate concentration in the soil leachate is 310 mg/l nitrate for the period 1968-2017. The historical fertilization pressure is rather average in Wortegem-Petegem. After full implementation of fertilization standards in the period 2007-2017, an average annual nitrate concentration of 174 mg/l nitrate was simulated. Due to the small proportion of forest, gardens and parks in this catchment, there is only limited dilution of nitrates leaching onto cropland and pasture.

The inflow of groundwater to the MAP monitoring point occurs mainly from the surrounding hills. These consist of tertiary sand (“Iepresian sand”, Formation of Tielt) on a deeper compact clay substrate and the sand in the hills is oxidized to a great depth. Consequently, the groundwater in these hills contains high nitrate levels, usually around 100 mg/l. Travel times of the groundwater from the hills are large can be up to 20 to 30 years. However, it was found that in the riparian zone, which is close to the stream itself, denitrification occurs due to the presence of organic material in the alluvial stream deposits. This still reduces nitrate input by about half. In the winter period, runoff rainwater causes dilution so that the highest nitrate concentrations occur in the summer.

3. <u>Balegem</u>

The average simulated annual nitrate concentration in the soil leachate is 310 mg/l nitrate for the period 1968-2017. The historical fertilization pressure is rather average in Balegem. With full implementation of fertilization standards in the period 2007-2017, an average annual nitrate concentration of 130 mg/l nitrate was simulated. There is some dilution of nitrates leaching onto cropland and pasture due to the significant proportion of forest and gardens and parks in Balegem.

Groundwater flowing to the MAP monitoring point in Balegem is supplied from a ridge of hills to the south. These hills consist of oxidized sands of the Lede Formation but are located more than one km from the monitoring point. Nitrate can spread in these sands but due to the distance the travel times are long, it can take up to several decades. This nitrate-rich groundwater seeps into a swampy wooded area in pools that drain into the stream. This nitrate inflow causes high values at the monitoring point.

4. <u>Brecht</u>

The average simulated annual nitrate concentration in the soil leachate is 389 mg/l nitrate for the period 1968-2017. The historical fertilization pressure is extremely high in Brecht, but the large proportion of forest and higher net precipitation in this watershed still reduces the average concentration somewhat. With full implementation of the fertilization standards in the period 2007-2017, an average annual nitrate concentration of 143 mg/l nitrate was simulated.

The groundwater flow in Brecht is very special because the phreatic layer here dries up every summer and so there is no flow anymore. As a result, washed-out nitrate cannot be drained away and remains in place until autumn. Due to the rise of the water table the flow is restarted and all present nitrate is removed in a short time. The phreatic layer is flushed, as it were. This special situation is caused by the underlying Campine Complex and may well be more common in the North Campine region.

5. <u>Overijse</u>

The average simulated annual nitrate concentration in the soil leachate is 107 mg/l nitrate for the period 1968-2017. The average fertilization pressure over the whole period 1968-2017 was the lowest of all catchments and there is a lot of dilution due to the large proportion of forest and gardens and parks. With full implementation of fertilization standards in the period 2007-2017, an average annual nitrate concentration of 96 mg/l nitrate was simulated. Despite the recently lower net precipitation, the concentration does not increase in this catchment because due to the loamy soil texture, the nitrate flux also decreases.

The groundwater supply to the MAP monitoring point comes mainly from water flowing from a single drainage pipe. This water flows into a pond that then overflows into the MAP monitoring point. The water from the drainage pipe comes from the Brusselian deposits (Formation of Brussels) in the hillside. Because the Brusselian sands have been oxidized, this water contains high levels of nitrates, usually a little over 50 mg/l. As a result, the monitoring point often shows exceedances of the 50 mg/l. The Brusselian water must have infiltrated a long time ago, it certainly does not date from recent years.

6. <u>Peer</u>

The average simulated annual nitrate concentration in the soil leachate is 366 mg/l nitrate for the period 1968-2017. The historical fertilization pressure is very high in Pear, but due to the relatively large proportion of forest, there is some dilution of nitrates leaching onto cropland and pasture. With full implementation of the fertilization standards in the period 2007-2017, an average annual nitrate concentration of 182 mg/l nitrate was simulated.

Well-permeable high terrace deposits occur on the Campine Plateau. These sands are oxidized, as is the Kasterlee Formation below them. As a result, the oxidation zone here is considerable and high nitrate levels occur to at least 10 to 20 m depth. Because the sands are well permeable, there is a significant groundwater inflow into the stream that is nitrate-rich throughout the year. Only seepage water flowing upwards from the deeper Neogene packages is nitrate-free and contains more iron. This can cause some dilution. The MAP measuring point here shows consistently high values. Only strong rainy days can cause reduced concentrations.

7. Lubbeek

The average simulated annual nitrate concentration in the soil leachate is 293 mg/l nitrate for the period 1968-2017. The historical fertilization pressure is rather low in Lubbeek, but the lower net precipitation in this catchment leads to a more limited dilution of nitrates, which do leach largely onto the sandy loam soils. With full implementation of the fertilization standards in the period 2007-2017, a relatively high average annual nitrate concentration of 203 mg/l nitrate was simulated.

The MAP monitoring point in Lubbeek is located in a valley between hills composed of sands of the Formation of Diest. In the valley itself, an underlying clay substrate consisting of the Boom Clay occurs shallowly. The surrounding hills contain nitrate-rich water that causes high nitrate levels in the MAP during the summer. Springs occur along the creek that drain nitrate-rich water from the hills into the creek. In the winter, more surface runoff rainwater occurs which dilutes the concentrations causing lower winter concentrations.

8. Asse

The average simulated annual nitrate concentration in the soil leachate is 194 mg/l nitrate for the period 1968-2017. The historical fertilization pressure is rather low in Asse and there is a significant proportion of forest. With full implementation of the fertilization standards in the period 2007-2017, an average annual nitrate concentration of 117 mg/l nitrate was simulated.

The MAP measuring point in Asse is located in a stream valley. The structure of the subsoil is varied. In the upper part of the valley groundwater flows in from the hills, in the middle part there is a shallow tertiary clay substrate consisting of the Barton Clay (Maldegem Formation) and near the MAP measuring point the clay substrate is absent and groundwater flows in from the sand of the Lede Formation. This is oxidized and contains high nitrate levels. There are several sources along the brook that supply water rich in nitrates, but it has been established that this mainly occurs via washed-out flow paths, the route of which is not known. The high nitrate levels at the MAP monitoring point are mainly caused by this source water.

9. Assenede

The average simulated annual nitrate concentration in the soil leachate is 422 mg/l nitrate for the period 1968-2017. The historical fertilization pressure is high in Assenede and there is little dilution due to a limited proportion of forest, gardens and parks. With full implementation of fertilization standards during the period 2007-2017, an average annual nitrate concentration of 164 mg/l nitrate was simulated. Due to a recent increase in net precipitation in this catchment, there is some dilution.

The MAP monitoring point in Assenede shows no exceedances of the 50 mg/l limit but has seasonal fluctuations with higher winter and lower summer values. This fluctuation is caused by a change in the groundwater flow situation. The subsoil here consists of predominantly sandy material up to at least 20 m depth. However, from a few meters depth, the sandy package contains organic material that reduces nitrate present. Shallow groundwater from the upper meters is therefore nitrate-rich, deeper groundwater is nitrate-free. In winter, the large groundwater recharge creates local shallow flow systems that drain shallow water to the stream and result in higher nitrate levels. In summer, due to absent groundwater recharge, these shallow flow systems fall away and the groundwater comes from a shifting sand ridge located more to the south. This groundwater has much longer and especially deeper streamlines that allow it to pass through the reduction zone and be nitrate-free. This explains the lower summer concentrations.

10. Heuvelgebied

The average simulated annual nitrate concentration in the soil leachate is 347 mg/l nitrate for the period 1968-2017. The historical fertilization pressure is rather average in the Hill Area. With full implementation of the fertilization standards in the period 2007-2017, an average annual nitrate concentration of 173 mg/l nitrate was simulated. There is only a small proportion of forest, gardens and parks so dilution is limited.

This test site covers an entire ridge in the Flemish Ardennes and was chosen as an example of a larger test area. Measurements show that the hills here consist largely of oxidized sediments which therefore contain large amounts of nitrate-rich water that has seeped in during the last decades. Calculations with a groundwater flow model of the hills show that the water in these hills is often decades on the way to the streams that rise on the flanks. Problematic MAP monitoring sites are often located on these flanks. The nitrate supply to these MAP monitoring points is from groundwater inflow from these hills. In winter, due to the slope of the valleys, surface runoff can cause dilution. Drains sometimes play a major role as well, as in the case of the Plankbeek in Kruishoutem that was simulated with the model.

Conclusions from the comparison of case-studies

A comparison of the system analysis and modeling of the different test sites reveals the four main influencing factors that explain the high nitrate concentrations at the studied MAP monitoring sites. In order of importance, these factors are:

Factor 1 Average nitrate concentration in soil percolate

The weighted average annual nitrate concentration in the soil leachate at a depth of 90 cm was calculated for all test areas (Figure 2). The evolution is shown for each 10 to 5 year period in Figure 3.

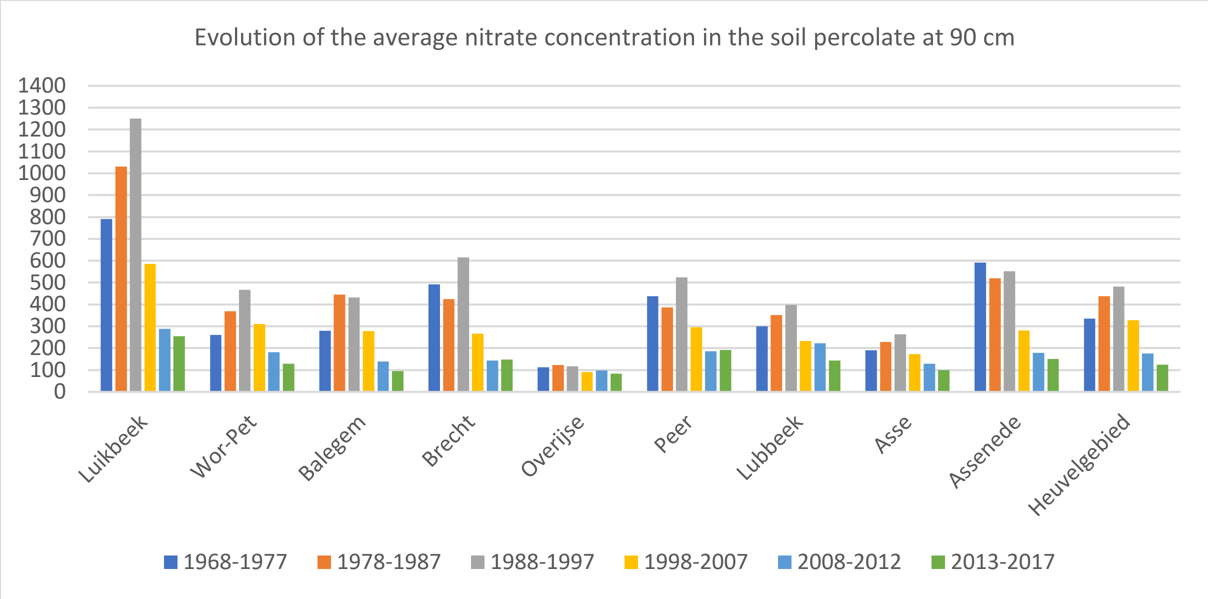

Fig 3 : Evolution of the average nitrate concentration in the soil percolate at 90 cm at catchmennt level, per time period of 10 to 5 years.

In most areas, the concentration initially increases due to the growing livestock population, and then decreases again, due to the gradual implementation of the fertilization standards in the simulations. **In all areas, the nitrate concentration in the water washed out of the soil is also recently, after implementation of the measures, higher than 50 mg/l nitrate.** The range during the last 5 years (2013-2017) is 86 to 235 mg/l nitrate and the last 10 years (2008-2017) from 92 to 260 mg/l nitrate (Table 1).

Testsite nr	Testsite name	5 years 2013-2017	10 years 2008-2017
1	Luikbeek (Staden)	235	260
2	Wortegem-Petegem	129	155
3	Balegem	96	117
4	Brecht	148	146
5	Overijse	86	92
6	Peer	192	189
7	Lubbeek	145	183
8	Asse	99	114
9	Assenede	151	165
10	Plankbeek (heuvelgebied)	143	169

Table 1 : Evolution of the average simulated nitrate concentration in the soil percolate at 90 cm at catchmennt level, per time period of 10 to 5 years

Nitrate concentration in soil leachate is strongly influenced by the following parameters: land use, fertilization intensity, share of different crops in the agricultural area , weather conditions and to a lesser extent soil texture and organic matter content:

- **Manure pressure historically determines the level of nitrate residues, nitrate leaching and nitrate concentrations on cropland and pasture (permanent grassland). In the proper application of fertilization standards, it is primarily the crops within the watershed that are the deciding factor.** For example, nitrate concentrations are much higher in the Liège brook drainage basin, where many potatoes and vegetables are grown, than in Wortegem-Petegem, where many winter cereals (whether or not followed by catch crops) are grown.

- **Utility of fertilization standards:** For the entire period 1968-2017, the long-term average nitrate concentration in the soil leachate was between 107 (Case in Overijse) and 786 mg/l nitrate (Case of the Luikbeek testsite). For the period 2007-2017, where maximum fertilization standards were applied in the model at the plot level, and where fertilization standards were increasingly tailored to crop needs, between 96 (Case in Overijse) and 282 mg/l nitrate (Luikbeek testcase). The decrease over time through implementation of fertilization standards is stronger in areas where initial concentrations were higher.
- **Local weather conditions help determine nitrate concentrations and the rate of leaching:** in some catchments in northern Flanders, dilution is greater due to higher net precipitation (precipitation minus potential evapotranspiration), while drier weather conditions in southeastern Flanders can lead to higher nitrate concentrations, especially on soils with a lighter texture. Similarly, the simulated nitrate residue on October 15 may be somewhat affected by mutually reinforcing differences in texture and precipitation: leaching may start earlier with a wetter late summer on lighter soils.
- **Dilution at the catchment level due to a higher proportion of forest and gardens and parks** has been demonstrated. Especially in the Overijse catchment, this contributes strongly to the average nitrate concentration in soil leachate, which is the lowest of all the catchments studied.
- The effect of the predominant soil texture of the catchment on the nitrate concentration in the soil leachate is less pronounced, partly also due to the interaction with the different weather conditions (sandy soils are more prevalent in northern Flanders). More nitrate generally washes out in catchments with lighter soil texture but there is also more dilution due to greater water percolation. The effect of changes in weather conditions is less in catchments with a loamy soil texture, because the magnitude of the nitrate flux changes more proportionally with it.

Factor 2: The presence of artificial drainage and the extent to which they drain shallow leachates

Drains capture water close to the water table which means that it is almost always water from the oxidation zone (where nitrate is not broken down) with high nitrate levels. Where the reduction zone (where nitrate is broken down) occurs shallow there may be some admixture of deeper reduced water through upward seepage to the drains, which causes a limited dilution and slightly lowers the nitrate concentrations. Nitrate measurements on drain water often give values above 100 mg/l nitrate. The presence of drains can only be deduced from field reconnaissance. There are no maps or databases with the location of all drains in Flanders. In many catchments where drains are the main nitrate input, MAP monitoring sites usually show a high seasonality with high winter values that can increase quite abruptly (at the beginning of the winter period) or decrease (at the end of the winter period). Examples are the test sites of Luikbeek (Staden) and Assenede.

There is a need for additional data on drainage: Drainage tubes are often not known, and there is a need for measurements of nitrate concentrations at drainage tubes to better assess the impact of drainage on surface water quality in areas with a lot of artificial drainage.

Factor 3: The thickness of the oxidation zone and the relative contribution of groundwater from the oxidation zone

The thickness of the oxidation zone, and the relative contributions of groundwater from the oxidation zone is determined by the hydrogeological structure and permeability of the deposits. The hydrogeologic zonation map (HHZ) can be used as a guiding tool. In the mapping tool, the occurrence of these layers is represented on a map. The contribution of groundwater from the oxidation layer can vary from very small, no more than a few percent as in the Luikbeek test site, to substantial , more than half, as in the Peer test site on the Campines plateau.

To determine when there is an important inflow from the oxidation zone, one can look at the seasonal fluctuations of the MAP monitoring points (see Fig 4).

It is therefore useful to classify the MAP monitoring points according to the seasonal fluctuations

- MAP monitoring points with winter maximum are usually strongly influenced by drains (example: Luikbeek), or by drought in summer (loss of baseflow)
- MAP monitoring points with summer maximum; supply of nitrate via groundwater from the oxidation zone. In winter this is diluted with runoff water (example: Wortegem-Petegem)
- MAP monitoring points with low seasonality. Constant inflow of groundwater without much dilution in winter
- MAP monitoring points with more complex flow situations. In the MAP network in Brecht the phreatic layer is completely dry in summer. In autumn the whole soil is washed out, causing peak concentrations. The MAP measuring point in Overijse is strongly fed by a drainage pipe that allows groundwater to flow directly to the MAP measuring point. These non-specific MAP measuring points should be considered in their local context.

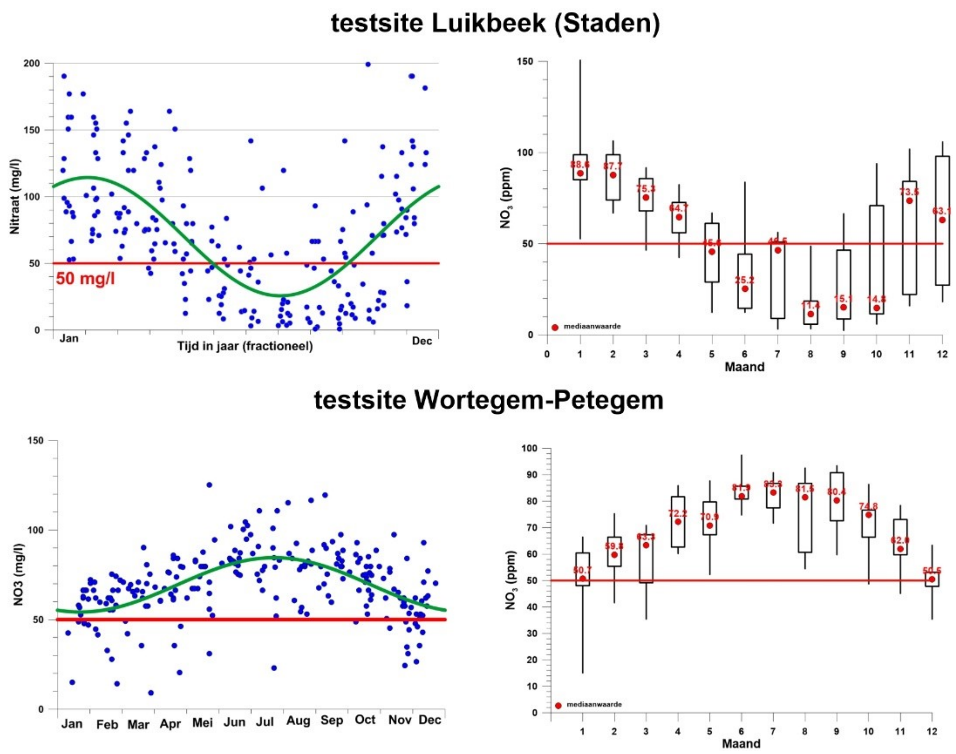

Fig 4 : Comparison of the seasonal variation at the MAP measuring points of the test sites Luikbeek (Staden) and Wortegem-Petegem

Factor 4: Groundwater travel times

Travel times of groundwater are only important when there is significant inflow from the oxidation zone. Indeed, the age of nitrate-free groundwater is completely irrelevant. The travel time of groundwater depends on the length of the flow paths it follows and the speed at which the groundwater flows. The more permeable the sediments are, the faster the groundwater will flow. Groundwater ages cannot be measured directly in a simple way. They can be derived from calculations using a groundwater flow model, but this is a cumbersome method. In this project, a groundwater model of three test sites was constructed and the age and travel time of the groundwater was calculated. The groundwater flowing into a stream consists of a mixture of younger water, infiltrated close to the stream, and older groundwater, coming from further away. The proportion of groundwater of a particular age decreases with increasing age. This distribution and the maximum ages depend on the test site and the hydrogeological situation. A simple indicator is the median age, which is the age at which half of the groundwater is younger and the other half is older. This directly indicates whether there is much older groundwater flowing into the MAP monitoring site, which has implications for response times for measures. If the median age is low, e.g. only a few years, then an effect of the measures is to be expected within 5 to 10 years, but if the median age is 20 years or more then no major improvement can be expected even in the coming decades. Only the age of the water in the oxidation zone needs to be considered. In the Luikbeek test site the oxidation layer is thin, no more than a few meters, and the median age was estimated at 3 years. In the Peer test site on the Campine plateau, the median age is between 15 and 20 years and therefore little effect of measures could be expected in a short time. The largest travel times occur at MAP monitoring sites in hilly areas. The inflowing groundwater comes mainly from the hills and these are largely composed of oxidized tertiary sand layers (e.g. Formations of Tielt, Lede, Brussels and Diest) that contain nitrate-rich water. Median travel times here extend to more than 20 years. Due to the mixture of groundwater of different ages, the effect of measures will also not manifest itself suddenly, but very gradually.

The study gives some methods to determine these travel times in different types of areas (refer to part of the report where this is discussed without explaining the methods here).

Possible actions

FACTOR 1 How to reduce the average nitrate percolation in the catchment?

It was indicated above that the nitrate concentration in the leached water from the soil is high in all areas. Taking into account that groundwater of different ages are mixed in the phreatic (upper) groundwater layer, this means that the nitrate concentration in the leachate is too high to fall below 50 mg nitrate/l without natural degradation (attenuation).

However, we can lower the average nitrate leachate in the basin by reducing nitrate inputs from agriculture.

There are many ways to influence and reduce nitrate percolation from agriculture. For example, judicious fertilization, following the 4R's (right dose, right time, right type of fertilizer and right application technique) can reduce nitrate residue.

In the project a calculation was made of one measure: sowing catch crops on all plots. Catch crops take up nitrogen in the soil in autumn, and can thus prevent this nitrogen from leaching out with the leachate in winter. In the spring, the catch crop releases the absorbed nitrogen back into the soil and the succeeding crop can then take it up.

A simulation in the Luikbeek catchment shows that the application of catch crops without adaptation of fertilization of the succeeding crops only has an effect on the nitrate load that leaches out. It does not reduce the nitrate concentration in the soil leachate. This is because the catch crop also causes extra transpiration which will reduce moisture percolation, and the extra release of nitrogen (mineralization) from the catch crop in the spring does not reduce leaching sufficiently to obtain a decreasing average nitrate concentration in the soil leachate.

If the fertilization of the succeeding crop is adjusted, whereby the fertilizer dose is reduced by the release of nitrogen by the catch crop, the nitrate concentration in the leachate, does decrease. In the simulation in the Luikbeek catchment, the sowing of a catch crop with adjusted fertilization of the succeeding crop reduced the nitrate concentration in the soil leachate by 43 mg/l nitrate, or by 10 and 15% for the period 1998-2017 and 2007-2017, respectively. This shows that in other catchments, where concentrations are already lower, similar measures can lead to relatively stronger decreases. The resulting average nitrate concentration in the soil leachate for 2007-2017 does remain high in the Luikbeek catchment at 240 mg/l nitrate.

➔ **Sowing a catch crop must go hand in hand with an appropriate fertilization of the succeeding crop that takes into account the nitrogen release of the catch crop in spring.**

FACTORS 2-4 Drainages, the thickness of the oxidation zone and the groundwater travel times

Factors 2 to 4 can be influenced to a lesser extent (drainages) or not at all (thickness of oxidation zone and travel times), but say something about the response times to surface measures (factor 1). Response times will vary from only a few years for MAP sites mainly influenced by drains, to decades for MAP sites located in hilly areas like e.g. the Flemish Ardennes. In order to be able to detect 90% of the effect of a measure taken at the MAP monitoring point, it is necessary to wait for approximately three times the median age of the groundwater. So if the median age is 5 years, the effect will only be largely realized after 15 years. For the Peer test site, for example, a median age of over 15 years was determined, here it can take 40 to 50 years before a measure will fully improve the MAP monitoring point. In the hill areas one will also have to wait decades for a noticeable improvement.

MAP monitoring sites located in valleys whose inflows come from hills with oxidized sediments have high travel times and the age of the groundwater, is usually on the order of 20 to 40 years. **Because of this slow change, response times are high and the effect of limited measures,** e.g. reducing nitrate levels by only 10 or 20%, **will be little noticed** among the interannual variation that occurs due to changing meteorological conditions. These MAP monitoring points often have a strong seasonal pattern with high summer values or show high nitrate concentrations year round.

MAP monitoring points where the nitrate source is mainly water from drains often show a seasonal pattern with high winter values and, have much shorter response times because the drain water is recently infiltrated water. Measures will certainly have a noticeable effect here within a few years, but since the drain water comes mainly from the oxidation zone, the nitrate levels are close to those of the soil leachate. Calculations have shown that the average nitrate content in soil leachate is still a factor of 2 to 5 above 50 mg/l. The concentration in surface water can only fall below 50 mg/l if

- there is large admixture of other water (reduced, nitrate-free deeper groundwater or from runoff);

- **And if the nitrate concentration in the leachate drops dramatically by taking measures at the level of nitrate input from agriculture. Only the latter is in our control.**

To get an idea which MAP monitoring points are mainly fed by oxidized groundwater (with long response times) or by drain water (with short response times) one can classify the MAP monitoring points according to the monthly median values of nitrate concentrations and a winter and summer index calculated from them. With the measured nitrate levels at the MAP monitoring point, median concentrations can be calculated for each month, e.g. for the last 5 or 10 years. A winter index is then the average of the winter months, the summer index of the summer values.

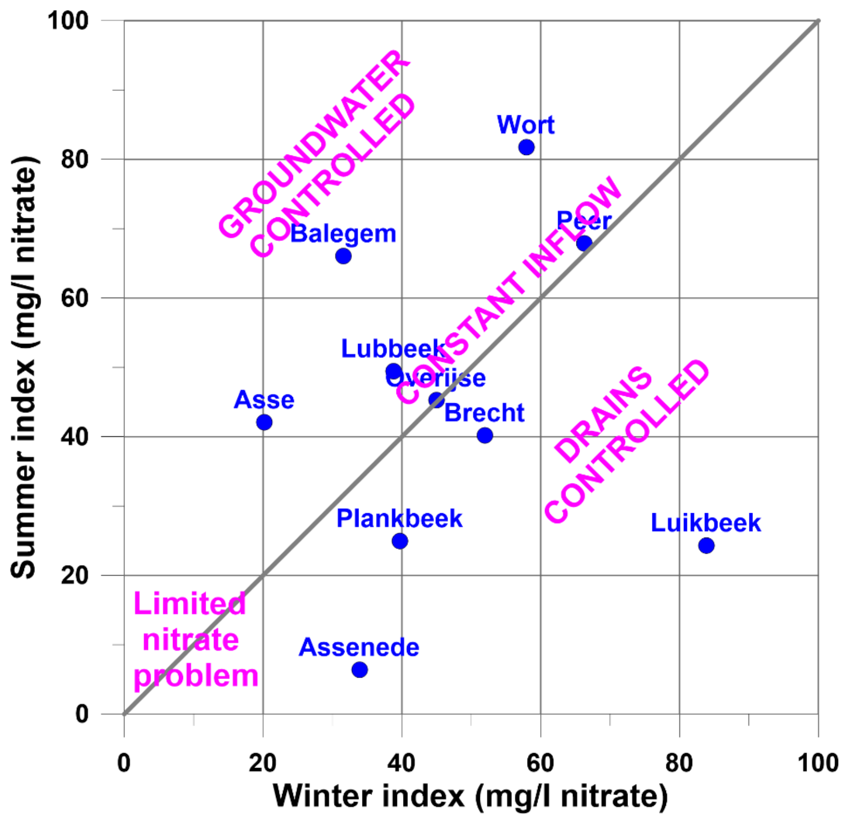

Fig 5 : Classification of the test sites on the basis of the winter and summer index of the median nitrate concentrations at the MAP measuring point