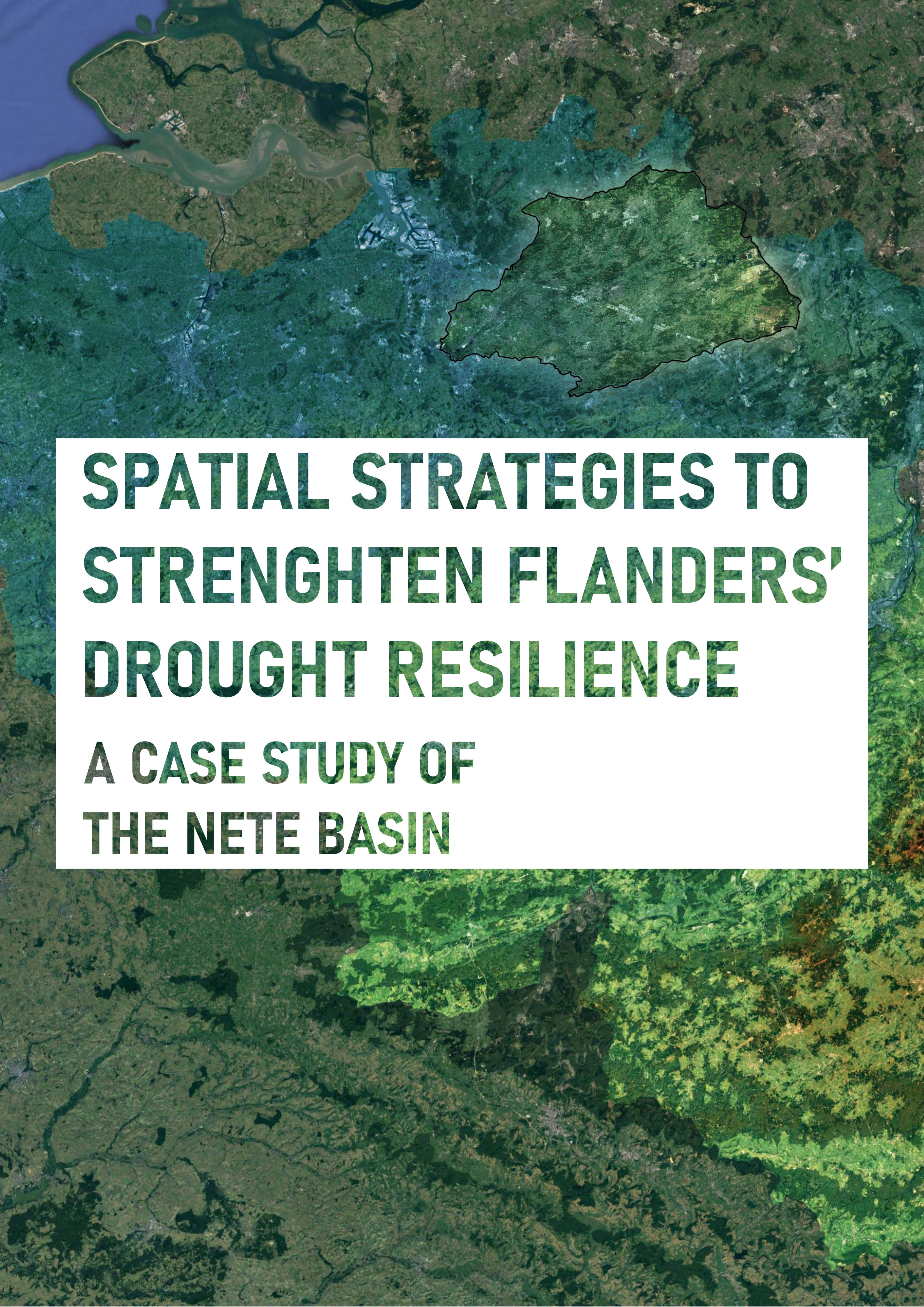

SPATIAL STRATEGIES TO STRENGHTEN FLANDERS' DROUGHT RESILIENCE

A CASE STUDY OF THE NETE BASIN

SPATIAL STRATEGIES TO STRENGHTEN FLANDERS' DROUGHT RESILIENCE

A CASE STUDY OF THE NETE BASIN

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VRIJE UNIVERSITEIT BRUSSEL

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PREFACE

With a background in physical geography, this thesis was an ideal convergence of my former and current master's programmes. As geography insights can frame and analyse the drought challenge, spatial planning and design provide practical solutions to increase Flanders' drought resilience.

Combining a full-time job as a high school geography teacher and the master's degree programme at the VUB proved to be challenging but worthwhile. Often, I included new insights from lectures at the VUB into my own lessons the next day. Looking back on the past three years, I want to thank all the lecturers, especially I want to thank my supervisors, Msc Nishtman Karimi and Prof Dr Kobe Boussauw, and my partner Iris Terclaevers, who often had to cope with my tedious thesis-writing moods

ABSTRACT (ENG)

Recent dry summers highlight Flanders' increasing drought challenge in the coming decades. Therefore, implementing thorough drought strategies is essential to improve Flanders' climate resilience. This thesis explores the possibilities for spatial drought strategies in the Campine region and researches different policies, stakeholders and academic insights to present potential drought mitigation strategies for different case study areas in the Nete basin. Firstly Flanders' drought challenge will be framed and defined. Afterwards, the second section of this thesis will look into Flanders' existing drought policy and illustrate that a long road still has to be taken to transform Flanders into a drought-resilient region. Still, promising policy trends are emerging, but the full impact remains to be seen.
This thesis's third and central section focuses on the Nete basin, especially the region along the Kleine Nete river. Due to its physical geography and land use characteristics, this region is essential in providing Flanders with groundwater. Therefore, developing spatial solutions to improve rainwater infiltration and retention is crucial to increasing the influx to groundwater reservoirs.

This thesis approaches spatial drought mitigation strategies with nature-based solutions. As nature builds resilience through complexity, diverse site-specific landscape transformations are vital in providing conditions for this complexity to develop.

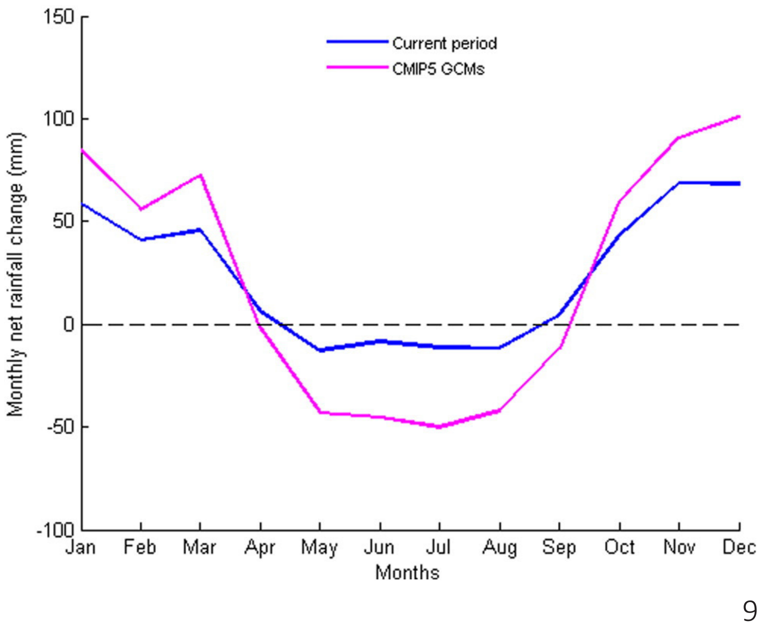
ABSTRACT (DUT)

De recente droge zomers maken duidelijk dat Vlaanderen de komende decennia met toenemende droogte te maken zal krijgen. Daarom is het implementeren van doeltreffende droogtestrategieën essentieel om de klimaatweerbaarheid van Vlaanderen te verbeteren. Deze thesis verkent de mogelijkheden voor ruimtelijke droogtestrategieën in de Kempen en onderzoekt verschillende beleidslijnen, stakeholders en academische inzichten om potentiële droogtebestrijdingsstrategieën voor te stellen voor verschillende case studiegebieden in het Nete bekken. Eerst zal de droogte-uitdaging van Vlaanderen worden gekaderd en gedefinieerd. Daarna zal het tweede deel van deze thesis het bestaande droogtebeleid van Vlaanderen onder de loep nemen en illustreren dat er nog een lange weg afgelegd moet worden om Vlaanderen om te vormen tot een regio die resistent is tegen toekomstige droogte-uitdagingen. Toch tekenen zich veelbelovende beleidstendensen af, maar de volledige impact valt nog te bekijken.
Het derde en centrale deel van deze thesis focust op het stroomgebied van de Nete, in het bijzonder de regio langs de rivier de Kleine Nete. Door haar fysische geografie en kenmerken van landgebruik vormt deze regio een essentiële sleutel in de grondwatervoorziening van Vlaanderen. Daarom is het ontwikkelen van ruimtelijke oplossingen om de infiltratie en retentie van regenwater te verbeteren van cruciaal belang voor het verhogen van de influx naar grondwaterreservoirs, die een belangrijke rol spelen in het veiligstellen van de watervoorziening van Vlaanderen.
Deze thesis benadert ruimtelijke droogtebeperkingsstrategieën met nature-based oplossingen. Aangezien de natuur veerkracht opbouwt door middel van complexiteit, zijn diverse locatiespecifieke landschapstransformaties van vitaal belang om de voorwaarden te creëren waaronder deze complexiteit zich kan ontwikkelen.

1. INTRODUCTION

Approximately two-thirds of the global population, four billion people, live under conditions of severe water scarcity at least one month a year, and nearly 500 million people are faced with water scarcity all year round (Mekonnen & Hoekstra, 2016). Moreover, 30% of the global population is estimated to reside in areas and regions routinely impacted by either flood or drought events. Especially agriculture is the economic sector most affected by the increasing variability of water resources globally (UNESCO World Water Assessment Programme, 2018). It absorbs 84% of adverse economic impacts of drought and 25% of all damages from climate-related disasters. According to the World Meteorological Organization of the UN, 50% of the 2.8 billion people who suffered from weather-related disasters between 1967 and 1992 can be attributed to drought (Kogan, 1997). In addition, the International Disaster Database (EM-DAT, 2018, as cited in (Natural Disasters - Our World in Data, n.d.) reports up to 1.5 million drought-related deaths in the mid-1960s and up to 450.000 deaths in the mid-1980s. Since the 1950s, human influence on the climate system has increased the chance of extreme weather events (Spinoni et al., 2014; IPCC, 2021). The Fifth Assessment Report (AR5) (IPCC, 2021) notes an increase in the frequency of concurrent heatwaves and drought on the global scale with high confidence and states that every additional 0,5°C of global warming, agricultural and ecological drought will increase (high confidence). The AR5 refers to Western Europa as a region that experiences drying. Today, 10-year drought events occur 1,7 times more likely compared to the 10-year drought event frequency between 1850 and 1900. Depending on future global warming levels, the frequency of a 10-year drought event will occur two times more likely with 1,5°C of warming, 2.4 times more likely with 2°C of warming and 4.1 times more likely with 4°C of warming per 10 years.

Tabari et al. (2015) analysed precipitation, potential evapotranspiration and water availability using historical simulations from 1961 to 1990 and future projections for 2071 – 2100 from the CMIP5 GCMs for Belgium. According to Tabari et al. (2015), Belgium will experience a change in water availability. The mean monthly precipitation and number of wet days in the summer season are projected to decrease and increase in the winter season under the RCP2.6, RCP4.5, RCP6.0 and RCP8.5 emission scenarios. "In other words, the wet season will get wetter and dry season drier, resulting in an increased risk of summer droughts and winter floods in the region" (Tabari et al., 2015). As a result, the cumulative water shortage could increase to 200 mm during the summer season (graph 1). This is especially of concern for Flanders



Graphe 1: Net rainfall for control period (1961–1990) and future period (2071–2100) of GMIP5 GCMs, for scenarios that lead to high positive precipitation changes in winter and high negative precipitation changes in summer (Tabari et al., 2015).

and the Brussels region as these regions are highly vulnerable to reduced water availability because of low water availability per capita. Flanders and Brussels have between 1100 and 1700 m³ of water per capita per year (Blue Deal - Integrale Tekst, 2020). Compared to other Western countries, this is relatively low. For example, among the OESO-countries, only Italy and the Czech Republic have less water per inhabitant. Even in countries such as Spain, Portugal and Greece, water availability per inhabitant is greater than in Flanders and Brussels (Waterbeschikbaarheid — Milieurapport Vlaanderen (MIRA), n.d.; Waterbeleidsnota 2020 - 2025, Deel Waterbeheerkweties, 2020). Therefore the implementation of effective adaptation strategies to increase drought resilience requires the attention of the responsible authorities. And thus, a well-thought-out spatial drought planning policy is necessary (Gullinck et al., 2012).

1.1 Defining drought

In contrast to the permanent climate condition of aridity, drought is a temporary phenomenon (Hisdal & Tallaksen, 2000). Namely, it is a deviation from normal conditions. "The chief characteristic of a drought is a decrease of water availability in a particular period over a particular area" (Beran & Rodier, 1985, cited in Hisdal & Tallaksen, 2000). Drought is a significant natural hazard that seriously impacts human societies and ecosystems (van de Vyver & van den Bergh, 2018). It can have a direct and indirect impact on terrestrial and freshwater ecosystems, agricultural systems, public health, water supply, water quality, food security, energy, or economies (e.g. through tourism, transport on waterways, forestry) (Hagenlocher et al., 2019; Schwalm et al., 2017). The occurrence of drought depends not only on atmospheric but also hydrological processes, such as evapotranspiration, which feeds moisture to the atmosphere (Hoa & Vinh, 2018). A low relative atmospheric humidity enhances evaporation and decreases the probability of rainfall occurring.

There is no single definition of drought (O'Hare et al., 2014). Wilhite and Glantz (1985, as cited in O'Hare et al., 2014) identified four different types of drought definitions: meteorological, hydrological, agricultural and socioeconomic drought. (1) Meteorological drought can be quantified or defined according to soil moisture deficit or precipitation (O'Hare et al., 2014). The thresholds to define drought are mainly geography-specific (by Hisdal & Tallaksen, 2000). (2) Drought can also be defined hydrologically by accounting for low river flow thresholds or water reservoir yield. (3) Agricultural drought can be identified by the number of consecutive days of reduced crop production due to crop stress and low relative soil moisture contents. This is the result of a combined shortage of precipitation and excess evapotranspiration, and in growing seasons, impinges on crop production of ecosystem functions in general (O'Hare et al., 2014). (4) Water supply and demand imbalances for some goods and services and discomfort to the human population refer to socioeconomic drought. In the agricultural and socioeconomic definition, drought results from an interplay between a natural event and the demand placed on water supply by human-use systems (Hoa & Vinh, 2018). Many regions are confronted with a higher water demand than the water supply. This imbalance is more profound around (semi-)arid river basins and is likely to increase due to hydrological water cycle changes resulting from climate change, adding further uncertainty and difficulty in predicting and planning water resources (Spinoni et al., 2014). Next to Wilhite and Glantz's four drought types, O'Hare et al. (2014) add another type: the ecological drought, which refers to negative consequences for wetlands, natural resources, and ecosystems.

1.1.1 The socioeconomic and bio-physical impact of drought

Drought severeness can be assessed with regularly updated indices. These are based on hydro- and meteorological conditions. For example, the Palmer drought severity index (PDSI) estimates current and past climates' aridity using temperature and precipitation data (Zhao & Dai, 2015). Another example is the standardised precipitation index (SPI). The SPI highlights the difference to the mean precipitation (expressed as a standard deviation) during a given time and therefore provides information on the severeness of drought conditions over a range of time scales (e.g. 3-; 6-; 12-; 24-months) (Mckee et al., 1993). Next to drought severeness, drought recovery is also an important metric to assess the impact of drought. Drought recovery can be seen as the time until hydrological drought ameliorates (Schwalm et al., 2017). However, the time of recovery for vegetation is critical for ecosystem functioning because if a new drought develops before full vegetation recovery, the probability of crossing a tipping point increases so that an ecosystem may transition to a new state. (e.g. anthropogenic activities and increasingly frequent droughts may cause local forest-savanna transitions in the Amazon Rainforest (Wunderling et al., 2020).

Bio-physically, drought damages natural habitats and landscape patterns, decreases soil productivity, reduces water quantity and quality, increases pollution and causes more wildfires (Azadi et al., 2018). Although, some of these effects could last a relatively short time. However, other effects can become permanent or strong enough to shift the agricultural arable land use to non-agricultural uses. Azadi et al. (2018) state that severe drought damages soil, reduces farm productivity and profits, and accelerates permanent agricultural land conversion to urban use. The reduction of productivity reduces farmers' income, increasing livelihood vulnerability and pushing farmers to migrate to cities. It should be noted that the push factor of drought for farmer-to-city migration is one of the many push and pull factors attributed to farmer-to-city migrations.

Drought can also degrade the landscape quality by impacting native vegetation that provides ecosystem services to farmers and communities and by reducing the phytomass ground cover and the number of plants, reducing the soil's protection from erosion (Torres et al., 2015). Therefore, soil erosion and drought are in a self-reinforcing loop, which reduces soil productivity. Still, the socioeconomic drought vulnerability index (Nishadi et al., 2009) presents a low vulnerability rate for Belgium due to the low employment rate in the agricultural sector and low contribution to the national GDP: agriculture facilitates 1% of the working population. It contributes to 1,9% of Belgium's national GDP in 2020 (Statbel, 2020).

1.2 Drought in Flanders

Most European regions, and Flanders, have experienced drought in 1976, 1996, 2003, 2006, 2011, 2017, 2018 and 2019. Several examples illustrate the consequences of drought in Flanders (Bressers et al., 2016). For example, in 2018, water pump facilities in the Albert Canal, which pump canal water upstream, were shut down to ensure sufficient canal depth for inland shipping (Belga, 2018). The droughts of 2018, 2011, 2006 and 1996 have also been recognised as agricultural disasters, resulting in farmers' financial compensations. Flanders also experienced wildfire problems related to drought. Wildfires in the nature reserve parc Kalmthouse Heide, north of the city of Antwerp, burned circa 600 ha in 2011 and 500 ha in the spring of 2021.

"Human-induced climate change has contributed to increases in agricultural and ecological droughts" (IPCC, 2021, p. 11) since the 1950s. This increase is also observed in West and Central Europe. "Every additional 0,5°C of warming causes discernible increases in […] agricultural and ecological droughts" (IPPC, 2021, p. 20). In the current climate, the number of consecutive dry days (CDDs) in Flanders ranges from 21 to 32. This is projected to increase. The most extended CDD period situates in 1893 with 44 days, followed by 2007 (37 days), 2012 (29 days), 1906 and 2020 (28 days). Trend analysis on yearly CDD-period data shows that the annual average CDD-period increased by 1,5 days per decennium (KMI - Koninklijk Meteorologisch Insituut, 2020). Due to climate change, more extended CDD-periods could be alternated by extreme precipitation events.

Researchers from the Royal Meteorological Institute of Belgium developed drought maps of Belgium (Zamani et al., 2016) and an index which expresses the (ab)normality of droughts for timescales from a month to a year (KMI - Koninklijk Meteorologisch Insituut, 2020; van de Vyver & van den Bergh, 2018). KMI (2020) estimated the impact of climate change on drought by applying this index to 15 regional climate projections. KMI (2020) looked at the meteorological droughts for the second half of the 20th century (2046 – 2100) for two emission scenarios (RCP 4.5 (medium-impact) and RCP 8.5 (business as usual)). The KMI (2020) research results show that there will be more drought periods by the end of the century in both RCP-scenario's. In addition, the research results show that the number of exceptional droughts (such as the one in 1976) can occur five times more frequently compared to the historical reference period (1951 – 2005). "Although these results are calculated based on precipitation data for all months, the expected decrease in summer precipitation lay at the basis of the increased drought probability" (KMI, 2020).

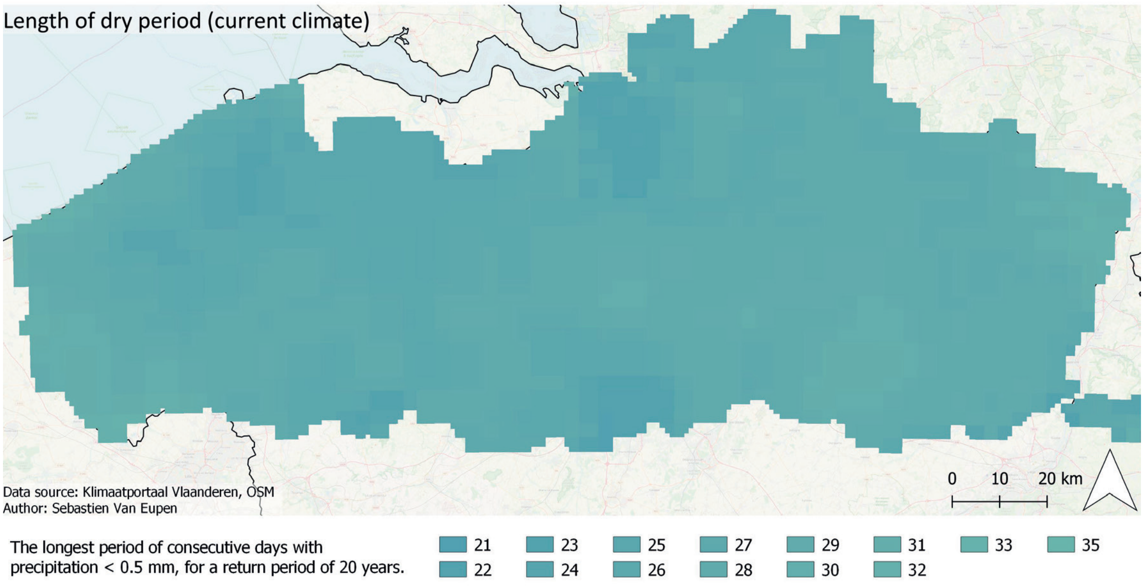
Complementary, the Flemish climate data presents a similar picture. The current and projected data (Kaartencatalogus — Klimaatportaal, n.d.) on the length of CDDs (consecutive dry days) periods (presented on map 1) shows complementary results. Climate Portal Flanders, which offered the data for map 1, analyses its projected data based on the high-impact business-as-usual scenario with an average global temperature increase of 3,2 – 5,4°C by 2100 compared to pre-industrial levels (Lokers et al., 2021). Furthermore, the length of CDDs periods, as a period of consecutive days with precipitation < 0,5 mm, is expected to increase from 21 – 32 days in the current climate to 128 – 152 days by 2050. The projected CDDs in Flanders by 2050 in a high-impact scenario can be compared to the average CDD range of 128 – 158 days in the Mediterranean climate of the Cyclades in the Aegean Sea today (Nastos & Zerefos, 2009). This evolution indicates severe consequences for agriculture and water supply in some areas of Flanders and Belgium (KMI, 2020). The drought during the spring of 2020 showcases a critical note that must be considered when examining drought. The cumulative precipitation of the spring season in 2020 did not deviate a lot from the mean. However, central Belgium was characterised as "severely dry". The relatively low air humidity and extensive cloudless periods resulting in many sunshine hours resulted in high degrees of evaporation, which was the main driver of drought at that time (VMM, 2021).

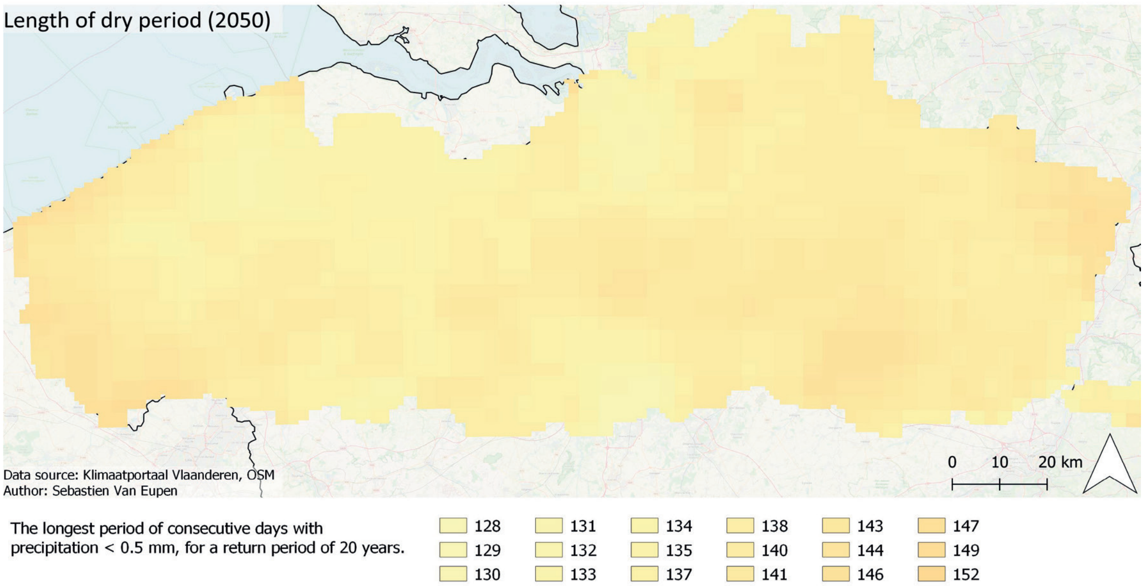
Map 2 indicates the potential impact of agricultural droughts in Flanders. The map's data and class distribution is based on soil texture and moisture conditions (Lokers et al., 2021). The average number of agricultural dry days in Flanders, where relative soil moisture content fall below the level at which crop production begins to experience stress 5,6 days in the current climate (Lokers et al., 2021). This number will increase to an average of 9,7 days in 2050 (map 2) and 19,8 days in 2100 in a high impact business as usual scenario. Note that map 2 presents a higher number of agricultural dry days in urban areas as soil moisture content is already significantly lower due extensive occurrence of impermeable land cover (Morgenroth et al., 2013).

Map(s) 1 : Annual length of dry period (CDDs) from the current climate and future projections in a high-impact business as usual scenario.

Mapped by Sebastien Van Eupen

Data source: kaarten-catalogus — Klimaatportaal, n.d.

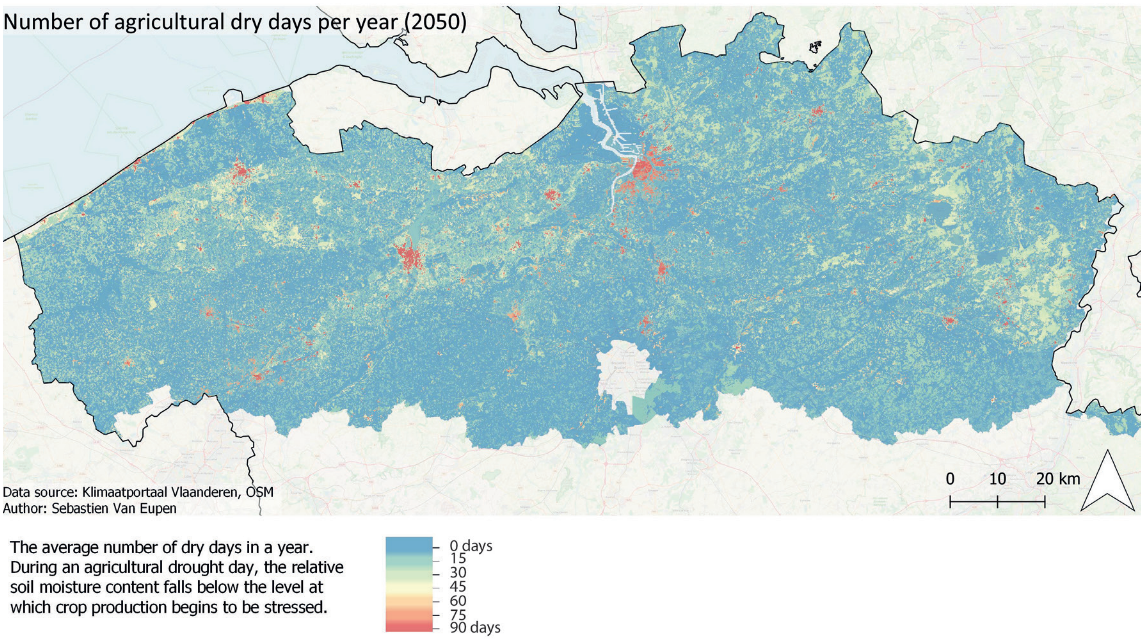




Map 2 : Projected number of agricultural dry day per year by 2050.

Mapped by Sebastien Van Eupen

Data source: geopunt.be, OSM



Map 3 and 4 present the drought vulnerability of ecotopes. Vulnerability indicates that vegetation starts to experience significant drought stress. The classes of ecotopes that are not vulnerable are not taken into account in the dataset.

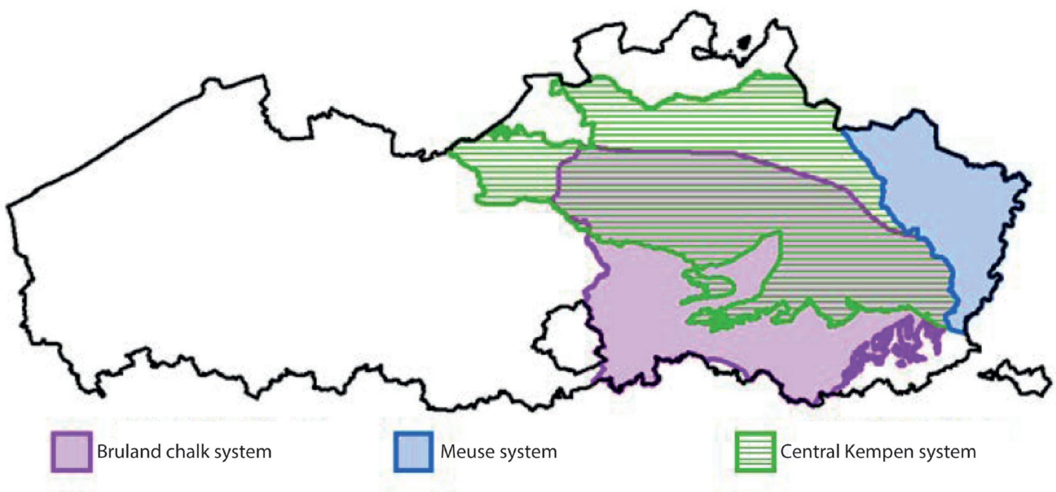
The number of vulnerable ecotopes subject to significant drought may increase from 3% (current climate, map 3) to 17% in 2050 (map 4). By 2100 a quarter (27%) of all the ecotopes in Flanders will become vulnerable to drought and could face significant drought stress in an average year.
Climate change leads to changes in future precipitation patterns (Lokers et al., 2021). An increase in the number of dry days a year results in drier summer with up to 60% less precipitation. Agriculture is especially vulnerable (UNESCO World Water Assessment Programme, 2018). Long periods of drought risk crop production, particularly in combination with limited irrigation water resources (Azadi et al., 2018; Lokers et al., 2021).

1.2.1 Drought and groundwater levels in Flanders
On the surface, the end of a drought period begins with precipitation (Landers, 2021). In this situation, the replenishment of groundwater levels experiences a lag time: the time needed for a change in rainfall or streamflow connected to surface water – groundwater systems to impact the groundwater level. Complementary, the recovery time indicates the time lag between the end of negative monthly precipitation anomalies and the time needed for groundwater levels to rise to the five-year average pre-drought groundwater levels (Schreiner-McGraw & Ajami, 2021). Notably, lag time works both ways. Groundwater levels can take much longer to respond to the effects of droughts (Landers, 2021). The length of the lag time depends on several factors such as soil texture, geomorphology, land cover and land use. 43% of the drinking water in Flanders originates from groundwater (Vlaamse Milieumaatschappij, n.d.).

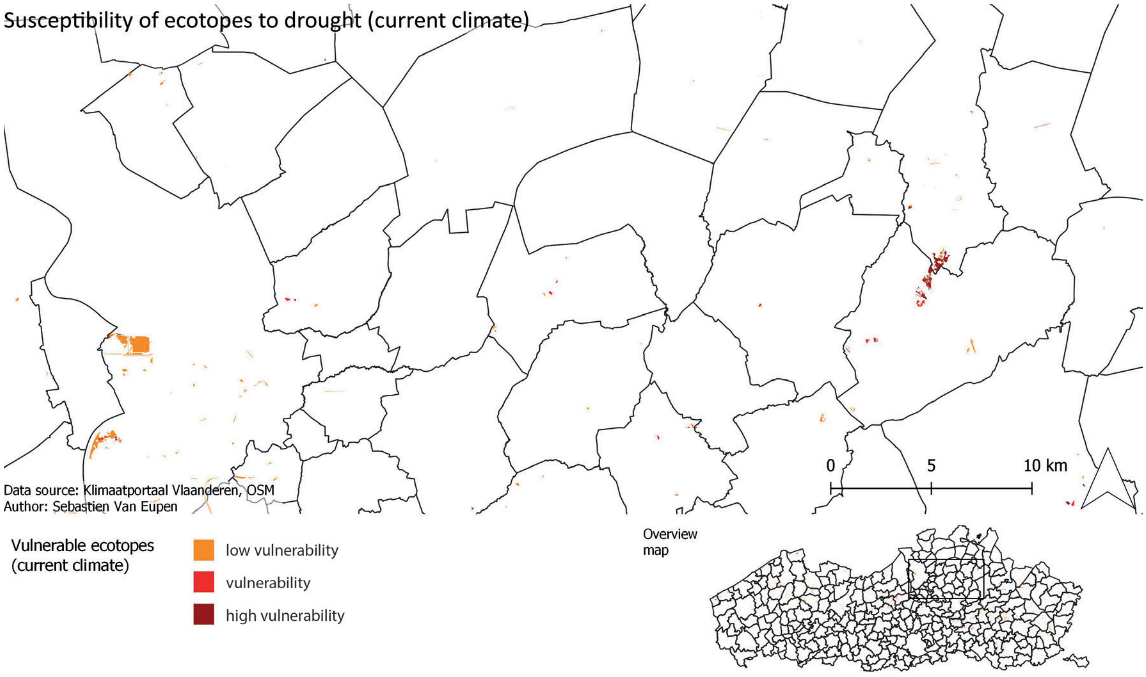
"In Flanders, there is quite a lot of pressure on groundwater due to groundwater extraction" (Gullinck et al., 2012, p. 68). The 22.600 groundwater licenses extract 420 million m³/year (figure 1). 282 million m³ originates from phreatic water layers dependent on rainwater infiltration for replenishment. 115 million m³ originates from deep non-phreatic groundwater layers. These are more vulnerable to extraction due to the relatively long replenishment time. The other 23 million m³ is not conscience.

In the north-eastern part of Flanders, the Campine region, 54% of all the drinking water originates from groundwater systems due to the permeable sandy soils (Vlaamse Milieumaatschappij, n.d.). Map 5 presents the locations of these three groundwater bodies from which most drinking water is abstracted.

Map 5: The three groundwater bodies from which most drinking water is abstracted Source: Vlaamse milieu-maatschappij, n.d.)



Map 3: susceptibility of ecotopes to drought in the current climate in Antwerp the city region and the Campine region. Mapped by Sebastien Van Eupen Data source: geopunt. be, OSM



Map 4: susceptibility of ecotopes to drought by 2050 for a high-impact scenario in the Antwerp city region and the Campine region. Mapped by Sebastien Van Eupen Data source: geopunt. be, OSM

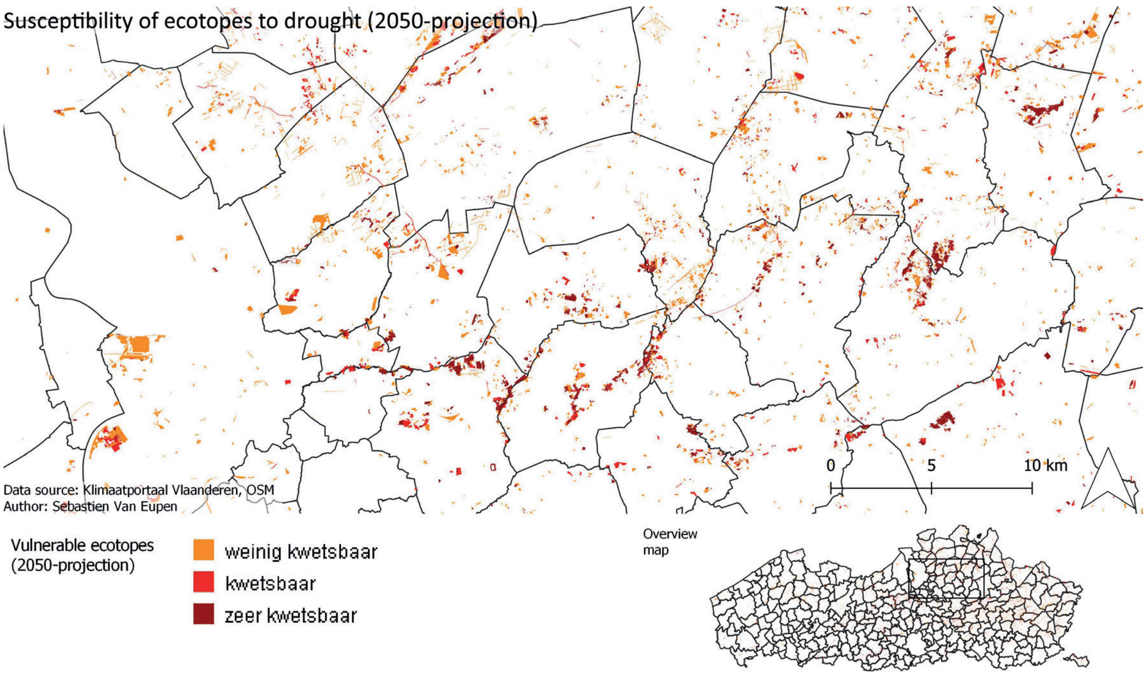
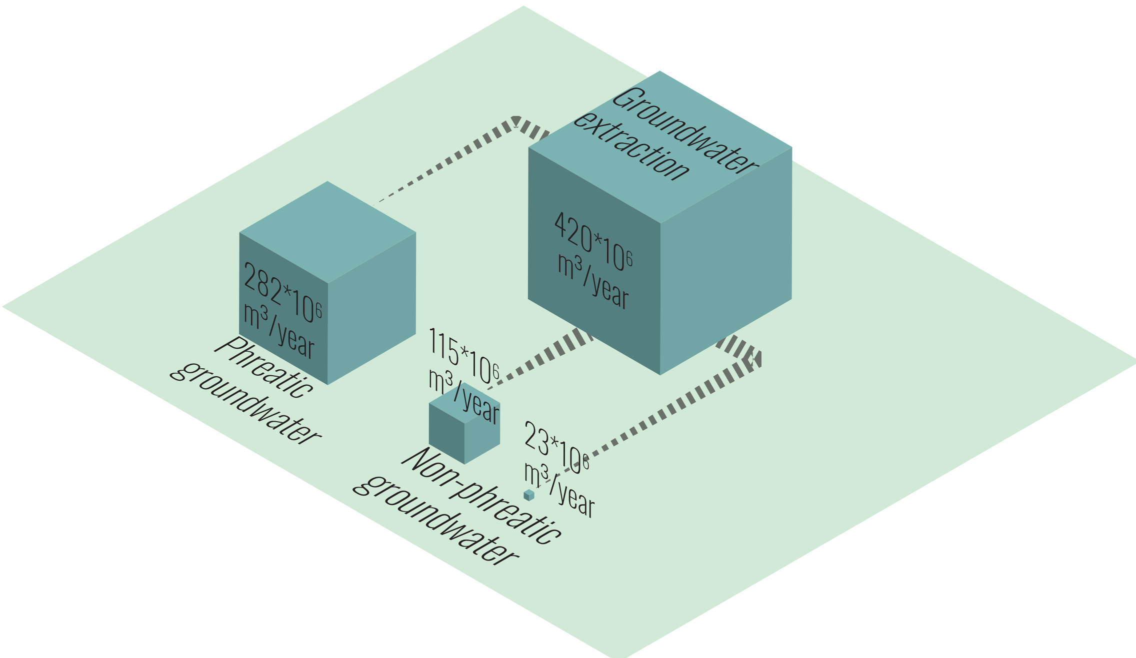


Figure 1: groundwater extraction sources in Flanders.

Image developed by Sebastien Van Eupen

Data source: Gullinck et al., 2012



The soil in the eastern part of Flanders is also the most susceptible to drought (see section 1.3). As a result, these groundwater bodies will receive significantly less water input from rainwater infiltration during drought periods. It is, therefore, crucial to monitor groundwater levels and their lag time to research the implications of drought in Flanders. DOV (Database Ondergrond Vlaanderen, Database Sub-surface Flanders) monitors, combines and analyses sub-surface data in Flanders. From 2000 until 2021, the last four years present increasingly extended drought periods with a relatively high percentage of low to very low phreatic groundwater levels. The wet summer of 2021 stands in sharp contrast with the previous years (Actuele Grondwaterstandindicator | DOV, 2021).

The spatial concentration of groundwater extraction in the east of Flanders can impact the area's hydrology. Especially in the Nete basin, where groundwater extraction licenses extract 19% of the infiltrated precipitation water (Gullinck et al., 2012). Next to illegal groundwater extraction and in combination with hotter and drier summers, the demand for groundwater, especially in the Nete basin, shall increase in the future.

Climate changes will, and shall to a more considerable extent in the future, depending on future emission scenarios, implicate precipitation changes in Western Europe, increasing the occurrence and duration of drought (IPCC, 2021). Precipitation changes can initiate drought and low groundwater levels, but surface and land cover characteristics can also significantly impact groundwater levels. "Extensive pumping from aquifers, reduced [groundwater] recharge due to urbanisation, and the pollution caused by human activities result in a negative impact on the quantity and quality of the groundwater" (Kronaveter et al., 2001). Urban development tends to increase surface runoff and decrease water infiltration. Current groundwater recharge losses are further enhanced by flood control projects, where a drainage system aims to quickly remove the runoff from built areas and tunnels it to waterways. Historically, water managers have paid more attention to mitigating the risk of flooding than drought risks (Bressers et al., 2016).

1.3 Spatial perspective on drought in Flanders

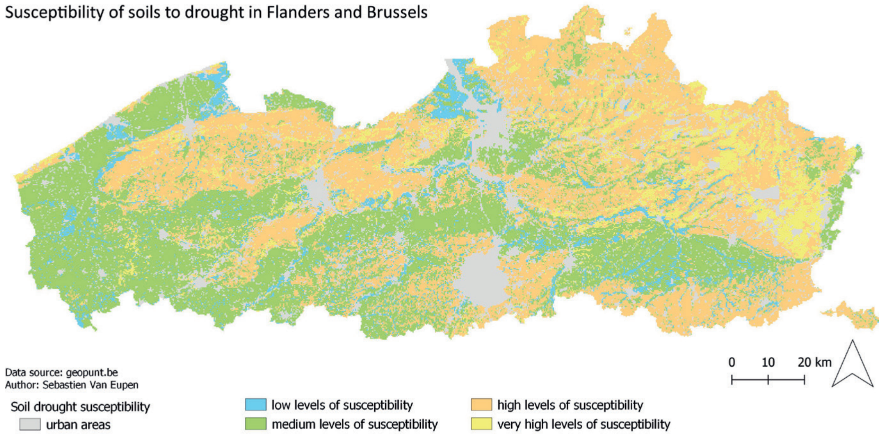
This section attempts to identify arguments to explain the spatial differentiation of drought susceptibility in Flanders and highlight areas especially susceptible to drought. Map 6 presents the land cover of Flanders (and Brussels), which is susceptible to drought. 48,85% of Flanders' and Brussels area experiences high (40,85%) to very high (8%) levels of susceptibility to drought. Especially, regions in the east of Flanders present high drought susceptibility levels. Map 7 presents data on potential infiltration-sensitive soils in Flanders. It identifies the areas in which rainwater can infiltrate into the subsoil relatively easily. Rainwater infiltration into the groundwater is essential because it reduces surface runoff (Davie, 2008). Furthermore, infiltration ensures the replenishment of groundwater reserves and thus counteracts the depletion of aquifers and the water-dependent nature. Infiltration sensitive soil covers 54,77% of Flanders (map 7). Although these soils are relatively equally distrusted over the Flemish region, some areas in the northwest and south of Flanders present a relatively large amount of soil that is not sensitive to infiltration. Map 8 and 9 present arguments to explain the spatial differentiation between soil infiltration sensitivities.

The southern part of Flanders corresponds to the more hilly areas presented on map 8. Higher slopes lead to lower infiltration capacities and higher runoff intensities, depending on soil and geological substratum (Pena et al., 2016). The coastal and north-western part of Flanders also presents low infiltration potential as well as dense urban and riverside areas. These areas have low infiltration capacities due to their soil composition and land

Map 6: Soil susceptibility to drought in Flanders (current climate).

Mapped by Sebastien Van Eupen

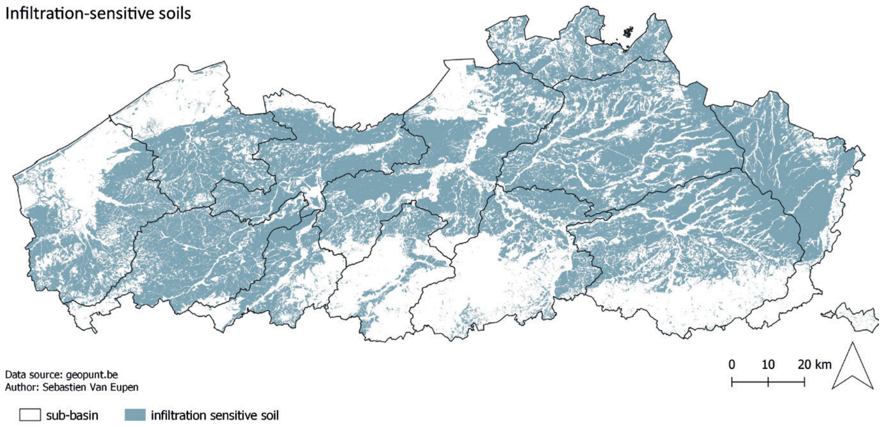
Data source: geopunt.be



Map 7: Infiltration-sensitive soil in Flanders

Mapped by Sebastien Van Eupen

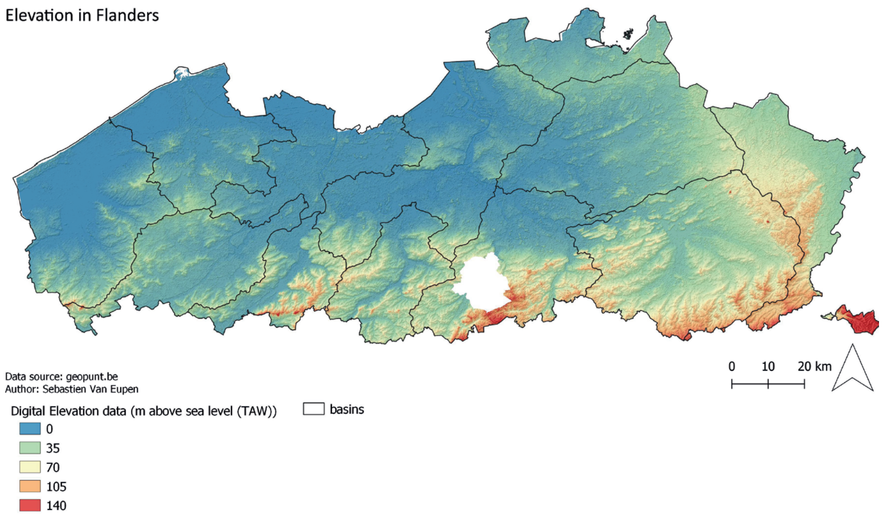
Data source: geopunt.be



Map 8: Elevation map of Flanders (DEM).

Mapped by Sebastien Van Eupen

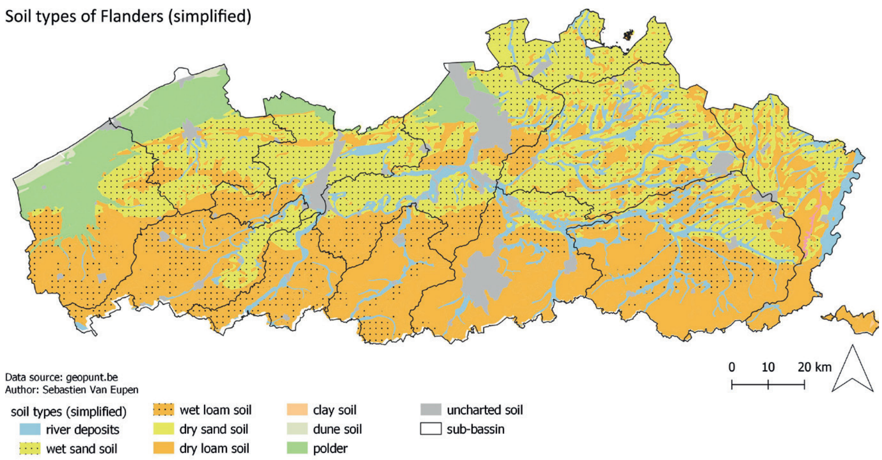
Data source: geopunt.be



Map 9: simplified soil texture map of Flanders

Mapped by Sebastien Van Eupen

Data source: geopunt.be



cover. The soil composition of the polders (map 9), the water-saturated alluvial deposits along rivers, and impermeable urban land cover all contribute to this area's low rainwater infiltration potential.
Additionally, map 6 presents the Campine region and Limburg as regions prone to drought. The soils in these regions have high levels of drought susceptibility. This can be attributed to this region's predominant sand soil textures (map 9) (Patrick Willems, n.d.). Sand has a lower water storage capacity due to a large particle size, which enhances infiltration and lowers the ability of the soil to retain water (van Hecke et al., 2013). Especially the region of the Limburg Plateau is the most eastern part of Belgium presents very high levels of drought susceptibility. This could be attributed to a combination of sandy soils (map 9) and a relative relief-rich area (map 8). The relatively hilly sandy soils in the Dutch region, bordering the Campine and Limburg to the north, indicate the same drought stress phenomena (Voorkeursstrategie Hoge Zandgronden | Gebieden | Deltaprogramma, n.d.). Different areas of Flanders are prone to drought, examining soil and elevation data suggest that drought adaptation measures should not just enhance rainwater infiltration, but also aim to improve soil moisture content overall by additionally improving soil water retention.

The infiltration rate is determined by the properties of the soil (hydraulic conductivity), vegetation cover and soil moisture content (Pena et al., 2016) There are two main situations where infiltration will not occur, which results in rainwater runoff. First, runoff can occur when the rainfall rate is higher than the soil's infiltration rate (Davie, 2008). Consequently, if soil infiltration capacity is low, runoff will occur readily. Generally, bare soils with small soil texture particle sizes (clay – loam) tend to have a low infiltration capacity than vegetation-covered coarse-particle-sized soils (e.g. forested or pastured loam-sand soil). Rainfall characteristics (rainfall intensity, quantity, raindrop dimension), slope position and land use are also determinants (Dunne & Leopold, 1978, cited in Pena et al., 2016). As explained in previous sections, high infiltration capacities do not guarantee low drought susceptibility.

"Accurate landscape planning has to consider water conservation" (Pena et al., 2016, p. 2). Incorporating water-related systems provides inclusion and possible protection of the hydrological cycle in spatial planning practices. Planning strategies to enhance infiltration and thus wetting the landscape provide essential functions of maintaining the water flow continuity, decreasing runoff and soil erosion, and contributing to the ground water supply. The regions with high and very high levels of susceptibility to drought are the sandy soils of the Campine region and northern parts of the provinces of West- and East-Flanders. East and West of Brussels, drought susceptibility is enforced by the sloping terrain and relatively small river valleys. In the future, dry river beds in these valleys may occur more frequently (Lokers et al., 2021).

1.4 Framing Flanders' drought challenge

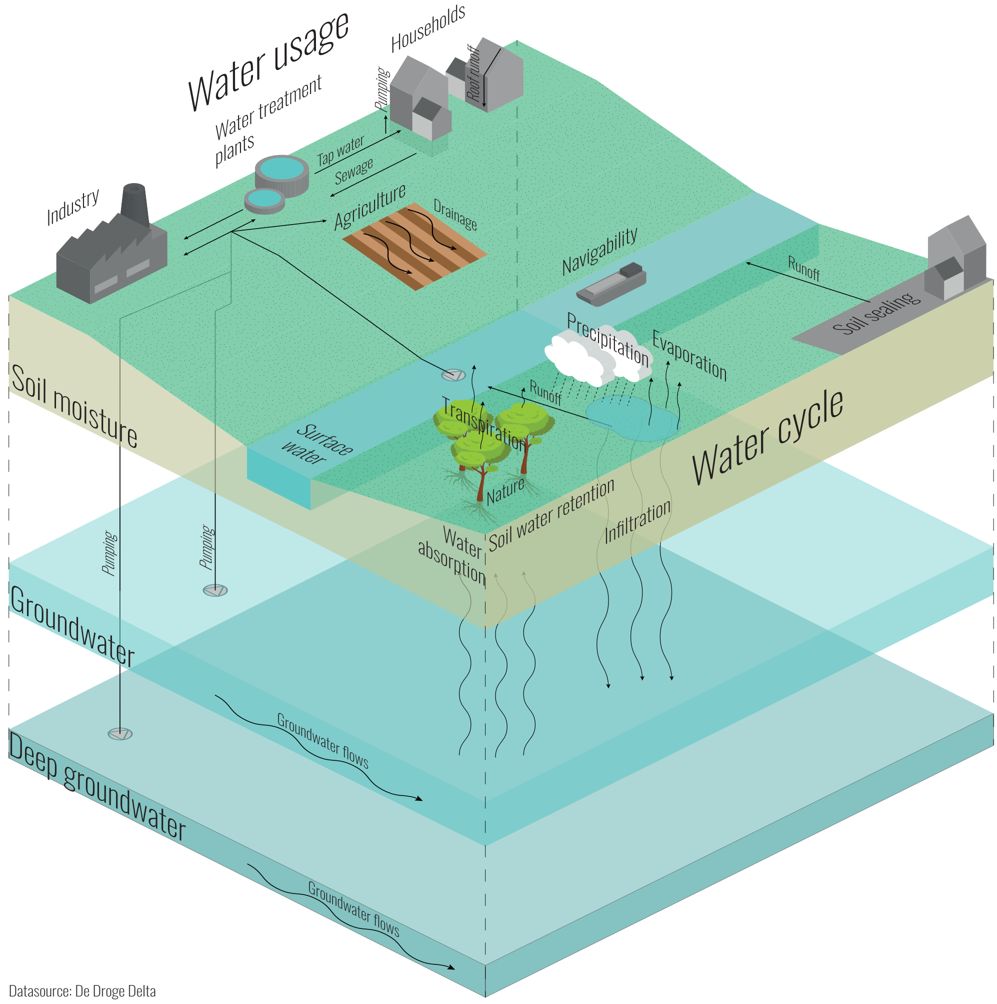
Historically, Flanders experiences 800 mm or 11 billion m³ of precipitation each year (Gullinck et al., 2012; KMI, 2020). Most of this water (63%) evaporates back into the atmosphere (figure 2) directly or indirectly via vegetative transpiration. 31% of rainwater discharges via waterways through direct surface runoff, which is also caused by soil sealing (see section 4.2), groundwater drainage and groundwater water flows. 3,5% of precipitated water discharges via sewage, and 2,5% is used for drinking water, industry and agriculture. Before it resurfaces in lower-lying areas, infiltrated water can remain as groundwater, potentially for decades. Due to this buffering mechanism, rivers and canals depend less on short term precipitation variations.

Belgium is ranked 23rd out of 164 countries in water scarcity, the third-highest in Europe apart from San Marino and Cyprus (The Bulletin, 2019). This index

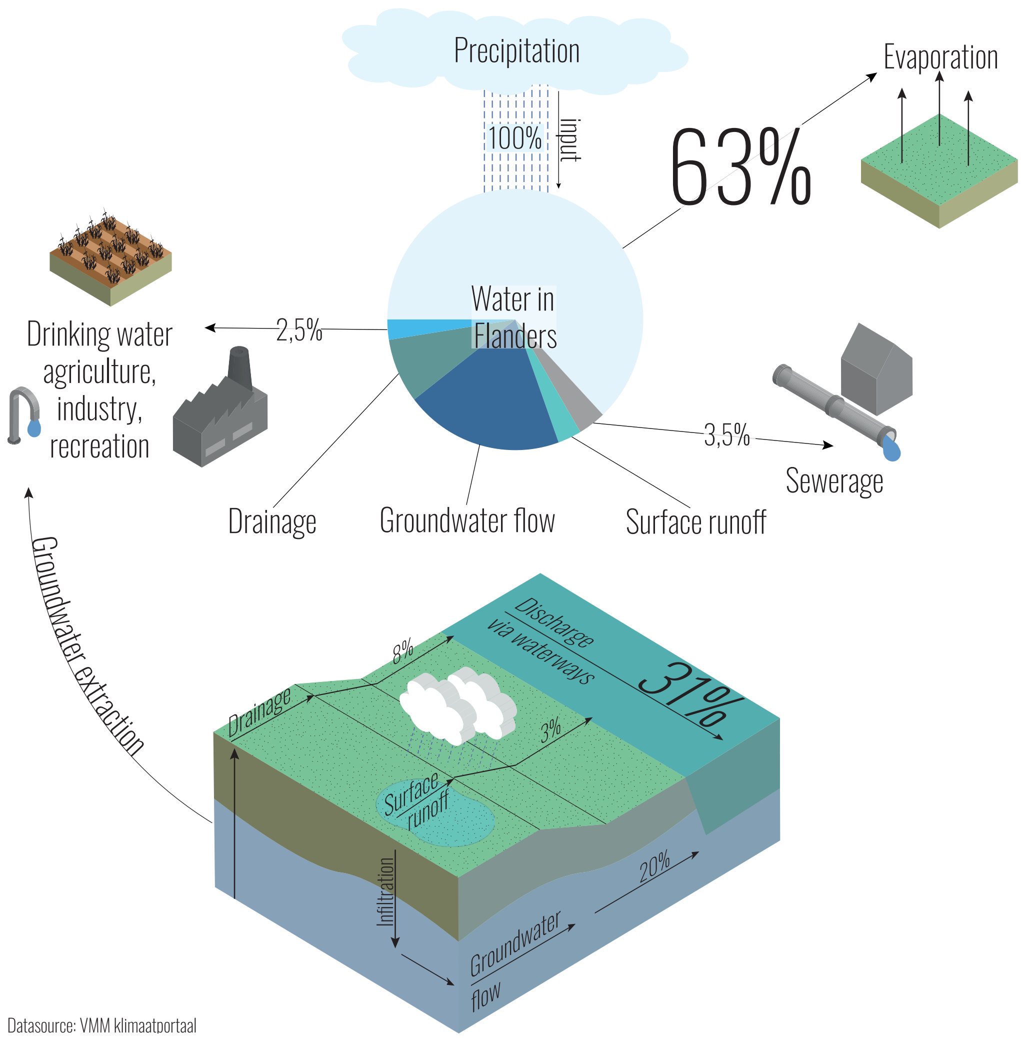
Figure 2: water cycle and flows in Flanders.

Data sources: VMM klimaatportaal, De Droge Delta

Image developed by: Sebastien Van Eupen



Datasource: De Droge Delta



Datasource: VMM klimaatportaal

represents the availability of water versus the water demand. High population densities and a lot of agriculture and industry of a relatively small area cause high water demands. There are no large rivers with a high water supply in Flanders.

Half of the drinking water is sourced from surface water, and the other half is sourced from groundwater (Huysmans, 2020). Groundwater is subdivided into shallow and deep groundwater (figure 2) Shallow groundwater is situated under the earth's surface and can reach tens of metres in depth. It is supplied by precipitation that infiltrates the soil and becomes a part of the groundwater flow (20%) (figure 2). Evaporation rates change according to the seasons. This is also reflected in groundwater level variations.

Consequently, shallow groundwater resupply is negligible during the summer months (Huysmans, 2019). Usually, Flanders' shallow groundwater shall restore during the winter months. But, the relative dry years of 2017, 2018, 2019 and 2020 illustrate that shallow groundwater levels could possible not be replenished after one winter season. Flanders' future summers are expected to become drier, and winters are expected to become wetter (Gulinck et al., 2012; Tabari et al., 2015; Verhofstede et al., 2012; IPCC, 2021). However, the total average yearly precipitation is not expected to change drastically, even during the summer months. Unfortunately, increasing intensity and decreasing duration of rain events present conditions where less water infiltrates into the soil to replenish groundwater levels. During high-intensity rainfall events in the summer, a relatively large portion of precipitation shall leave the Flemish territories due to evaporation or via surface runoff and waterways.

Additionally, soil sealing (16% of Flanders' surface) also contributes to surface runoff and less rainwater for groundwater replenishment. Additionally, there is a significant spatial difference in Flanders in the capacity of the substrate to store water. Sandy soils are more appropriate for storing water due to relatively large pores between the grains, enhancing rainwater infiltration and groundwater extraction via pumping systems. Consequently, the Campine region's sandy soil has to potential to be more resilient to climate change impacts than East- and West-Flanders' clayey and loamy soils. In these provinces, the water reserve is smaller. Due to impermeable ground layers, deep groundwater is separated from shallow groundwater (e.g. clay layer). Therefore, in the short term, surface water supply variations do not impact these deep groundwater layers (Huysmans, 2020). However, last decades, pumping from deep groundwater layers has already occurred. For example, deep groundwater pumping from the textile industry in the previous century causes a substantial reduction in available deep groundwater in West Flanders. Currently, remediation policies are in effect to restore deep groundwater layers, but the impact of these policies shall only be noticeable on deep groundwater levels after several decades. Therefore, addressing deep groundwater layers as a new water source is not an appropriate strategy.

There will be a need to create spatial planning strategies to buffer water to cope with the increasing intensity of dry and wet periods (de Sutter et al., 2012). Developing spatial strategies to increase the resilience of the hydrological system has economic and ecological incentives (de Sutter et al., 2012). An increasing population combined with reduced groundwater recharge due to further urbanisation shall further divert the demand and supply for water. The susceptibility of rivers to drought has become more extreme over the years due to the reduced sponge functions of valleys due to drainage, increased runoff due to soil sealing and other landcover that enhances runoff. There is an increasing chance that climate change will exceed (more) critical points causing economic and ecological damage.

The agricultural sector shall feel the most severe economic impacts of drought (UNESCO World Water Assessment Programme, 2018). Many Habitat Directive areas are situated in the Campine region (de Sutter et al., 2012). The river valleys in the more hilly eastern part of the Campine region present a relatively large forested area, resulting in high-quality groundwater. Paradoxically, this increases the pressure on groundwater by extraction, adding to drought susceptibility. The resulting groundwater level drops cause the surface to be more suitable for water infiltration causing drier conditions in the topsoil. Therefore, de Sutter et al. (2012) propose spatial planning strategies that retain more water in the soil.

Reducing runoff and holding rainwater in these regions could allow more rainwater to infiltrate the soil and reduce flooding impacts in lower-lying areas. Complementary, the resulting wetter areas could create conditions for biodiverse wetland ecosystems. This enhanced infiltration and retention capacity could contribute to Flanders' resilience towards extended drought periods.

In this section, Flanders' drought challenges are only framed from the perspective of the hydrological cycle (figure 2). This thesis focuses on rainwater infiltration and retention, especially in the Nete river basin. This approach is elaborated in section 4. It must be recognized that, besides infiltration and retention, there are other drought strategies such as increased water efficiency in agriculture, industry and households. Additional water reservoirs could be developed for water storage. The company Covestro is also investigating implementing desalinization plants in the port of Antwerp for industry (de Roo, 2021). These examples indicate that drought mitigation and adaptation is not exclusively a spatial planning challenge, but this thesis focuses on the spatial planning strategies to mitigate drought in Flanders.

1.4.1 Research question

Economic and ecological arguments incentivise the need for increasing Flanders' drought resilience (Gullinck et al., 2012). de Sutter et al. (2012) indicate that making maximum use of the potential precipitation surplus to replenish groundwater resources could be a strategy to secure water supplies and, at the same time, protect the remaining groundwater-dependent nature from further degradation. "The strategy of preferential local infiltration and subsequent retention of runoff water in the upstream river regions and depressions in the landscape is also complementary to the strategy to mitigate flooding resulting from extreme precipitation" (de Sutter et al., 2012, p. 72). Therefore, this thesis' primary focus is on these upstream water infiltration and retention strategies. The previous sections framed the concept of drought and Flanders' drought challenge. The following section, section 3, aims to provide an overview of the existing drought policy in Flanders and to answer the following research question regarding Flanders' drought policy:

- Does Flanders' drought policy lean towards a protective, preventive or preparedness approach?
These approaches will be elaborated on in section 3.

This thesis examines spatial planning strategies in the Nete basin, Campine region, Eastern-Flanders. Specifically, the potential to improve rainwater infiltration and retention to enhance Flanders' resilience to drought. The following research questions will be considered:

- Which spatial drought strategies could be implemented, considering relevant stakeholder demands and physical characteristics of the area (geomorphology, hydrology, land cover)?
Some site-specific concepts will be developed in further detail.

- Which relevant policy instruments are present to facilitate these site-specific concepts in the Nete basin?

The two main sections of this thesis, existing policy and spatial drought strategies in the Nete basin, aim to frame the importance of the drought challenge in Flanders and present a case study along the Kleine Nete river with a practical GIS approach to what drought strategies and where they can be implemented while considering relevant stakeholders.

2. METHODOLOGY

Firstly, a literature review will be conducted to examine the current drought policy in Flanders. Relevant literature for this section mainly focuses on policy documents but shall be supplemented with academic research papers. Furthermore, Actieplan Droogte En Wateroverlast 2019 – 2021 (2019) presents three policy approaches to drought (and flooding): a protective, preventive and preparedness approach. Drought policy in Flanders will be reviewed en subdivided into these three approaches to present a framework of Flanders drought policy approach.

Secondly, this thesis will zoom into the drought challenges of the Campine region and, more specifically, the river basin of the Kleine Nete. Map 6 already presents the Campine region in the east of Flanders as a region that has a high susceptibility to drought. Lessons learned from the literature study shall be considered to develop spatial drought resilience strategies for this region. Relevant literature, insights from data analysis, using Microsoft Excel, and GIS analysis (using QGIS) will be supplemented to a case study research of a section of the Nete basin. The governmental website Geopunt (geopunt.be) provides a whole range of GIS data sets relevant for drought strategy development in the de Kleine Nete basin.

Insights from researchers, such as de Sutter et al., 2012; Dewaelheyns et al., 2012; Dewaelheyns & de Waegemaeker, 2012; Dewaelheyns & Foré, 2012; Foré et al., 2012; Gulinck et al., 2012; Staes et al, 2021; Verhagen & de Blust, 1995 and Verhofstede et al., 2012 form a basis to develop concepts to mitigate drought. QGIS, Adobe Illustrator and Adobe Photoshop are the primary tools for developing these concepts. Additionally, spatial policy documents such as Spatial Implementation Plans (RUPs) shall be considered to explore stakeholder demands. Active stakeholder interviews were not conducted in the scope of this thesis.

Unless specifically mentioned with a reference, all maps, figures, diagrams and graphs are developed by the author of this thesis, Sebastien Van Eupen. Data sources are referenced under these maps, figures and charts.

3. DROUGHT POLICY IN FLANDERS

Temporal and geographical differences between a drought and flood crisis demand different approaches. In contrast to floods, a slower build-up characterises drought, but drought could last over a more extended period. Floods tend to concentrate on specific areas. The 2021 summer floods in the region of Wallonia are a prime example: valley systems with stony, water-saturated soils enhanced water runoff, resulting in high river flow rates and alluvial floods in the villages Pepinster and Verviers (Verstraeten, 2021). In contrast, drought events tend to cover larger regions (e.g. the record drought period of 2018 covered the western and central part of Europe north of the Alps (Buras et al., 2020)). Overall, water users, managers, and policymakers agree on the importance of protecting water resources to guarantee the long-term availability and quality of water. Spinoni et al. (2014) state that this is often not reflected in how water resources are planned, managed, and used at local, regional, and national scales.

The EU policy level has been crucial in providing the impulse to change water management in Flanders (Bressers et al., 2016). In 2000 the Water Framework Directive (WFD) introduced a more holistic approach to ecosystem-based water management by focussing on multiple relationships between causes of pollution and the different impacts on water in river basins (Water Use and Environmental Pressures — European Environment Agency, 2020). The WFD's aim is to establish that human water usage is compatible with the environmental dynamics. The WFD focuses on water quality and water quantity. Concerning water quantity and drought, the WFD requires identifying significant modification of flow regimes through regulation and morphological alterations. Although the WFD does not have a specific article on drought impacts, reference to "prolonged droughts" in Art. 4 and "conditions that may call for supplementary measures of water demand management" in Art. 11 provide cover for drought-related policies (Do-Ó, 2007). Flanders' drought policy is based on the implementation of the guidelines set out by the WFD (Bressers et al., 2016).

The following sections present Flanders' existing drought policy and indicate if the policies tend to have a protective, preventive or preparedness approach. The difference between these three approaches will be elaborated on in section 3.8.

3.1 Decree on Integrated Water Policy and the Flemish Water Policy Note

Three Flemish ministries are involved in integrated water policy: the Ministry of Spatial Planning, Mobility, and Environment and Nature. In addition, the Flemish Environmental Agency (VMM, Vlaamse Milieumaatschappij) receives many tasks related to integrated water management. The Decree on Integrated Water Policy of 18 July 2003 categorises the organisation and planning of integrated water management on three levels: the two international river basin districts of the Meuse and the Scheldt, the Flemish region, which contains the four river basins (from west to east) Yser, Polders of Bruges, Scheldt and Meuse and the eleven sub-basins (map 10). This decree covers surface water, groundwater, and water-related infrastructure (e.g. bridges, dikes, locks, and dams).

The Meuse river basin extends over five member states of the European Union (Belgium, France, Germany, Luxembourg and Netherlands) and extends over the regions of Flanders and Wallonia. The Meuse Discharge Treaty of 1995 provides a framework for multilateral coordination in the international river basin of the Meuse (Bressers et al., 2016). In addition, this treaty provides coordination for the implementation of the Water Framework Directive (WFD).

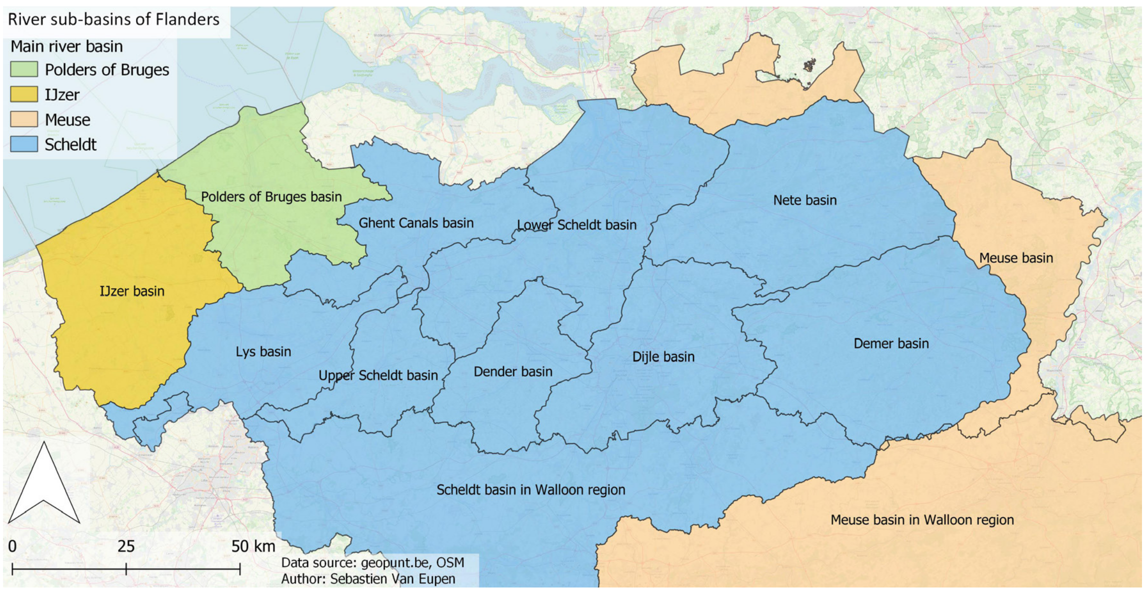
The Flanders drought policy is based on implementing the guidelines from the WFD. The Decree on Integrated Water Policy is the implementation of the WFD, but it also covers aspects of integrated water policy that are not legally required by the WFD (Bressers et al., 2016). Additionally, it contains the juridical implementation of the Floods Directive from 2010, detailed planning on the sub-basins level and spatial planning instruments. Some of these instruments have implications for drought measures. For example, the water test is a spatial planning instrument that assesses if a subdivision or building permit would potentially significantly influence the water system.

Besides delineating and protecting river banks, spatial instruments of the decree of integrated water policy encompass the instrument mix of real estate acquisition, purchase obligation and compensation obligation and the information obligation for real estate in flood-prone areas (Decreet Integraal Waterbeleid — Nl, n.d.). In addition, the Coordination Committee on Integrated Water Policy (CIW, chaired by the Flemish Environmental Agency, VMM), implements the WFD and Flood Directive (Bressers et al., 2016). The CIW also reports to the European Commission on the WFD implementation.

Map 10 River basins of Belgium and sub-river basins of Flanders.

Mapped by Sebastien Van Eupen

Data source: geopunt.be, OSM



The (third) Flemish Water Policy Note contains the goals regarding water management for the years 2020 – 2025. Concerning drought, the Flemish Water Policy notes that "concerning climate change, which results in more frequent heatwaves and longer periods without precipitation, the fact that the demand for water in Flanders does not seem to be decreasing much and the various evolutions that threaten to further reduce the availability of water in Flanders (e.g. increase in paved surfaces) results in an increased risk of water scarcity" (Waterbeleidsnota 2020- 2025, Deel Waterbeheerkweties, 2020).

The drought periods of 2017, 2018 and 2019 highlighted the vulnerabilities in Flanders: the estimated loss for agricultures as a consequence of the drought of 2017 amounts to 98 million euros; restrictions on inland shipping due to draught limitations; production uncertainties and stricter discharge standards for industrial sewage; more frequent episodes of blue-green algae formation and high fish mortality; and drying natural areas. Nevertheless, during the drought of 2017, "the water supply was not yet compromised" (Waterbeleidsnota 2020 – 2025, Deel Waterbeheerskwestie, 2020, p.13).

3.2 Coordination Committee Integral Water Policy, CIW

In June 2017, former Flemish environmental minister Joke Schauvliege appointed CIW (Coordination Committee Integral Water Policy) as the central drought coordinator of Flanders (Overleg Binnen de Droogtecommissie — Nl, n.d.). The CIW's primary objective is to coordinate and organise the integrated water policy under the responsible Flemish minister. The CIW, chaired by the VMM, is a multi-disciplinary commission that unites different water management and governance levels and enables a uniform approach to managing each river basin (Bressers et al., 2016).

CIW monitors drought indicators and formulates advice to manage drought events, and from this, the minister or provincial governor can announce appropriate actions to mitigate potential drought events. Model predictions and data on precipitation, river discharge, groundwater level and water quality are processed into an indicator that presents the current drought situation and its potential impact. The drought indicator can shift between 4 levels. Level 0 signifies a normal situation. Level 1 indicates the need for preventive measures by the drought commission of CIW, and at level 2, the drought commission formulates measures, communication and advice towards the provincial governor or minister. At level 3, the Flemish or provincial crisis cells coordinate and communicate actions and measures around drought management. During periods of drought, the drought commission, which is embedded into the CIW, organises consultations between different water authorities and governments to improve alignment between various measures between water authorities. The drought commission includes representatives of the Flemish Waterway, VMM, provinces, cities and municipalities, drinking water companies, Aquafin and the governors. The CIW chairman presides over this commission, supporting its decisions on the Assessment Framework for Priority Water Use.

3.3 Assessment Framework for Priority Water Use

The main goal of this assessment framework is to aid the development of well-considered decisions on measures to limit the probability of water scarcity, considering its socio-economic and ecological consequences during periods of extreme drought in (parts of) Flanders (Uitwerking van Een Reactief Afwegingskader Voor Prioritair Watergebruik Tijdens Waterschaarste, 2021). Furthermore, this framework provides ministers and governors with objective information on which further decisions could be based. Besides the previously mentioned drought indicators, the Assessment Framework for Priority Water Use also considers water supply and demand and different potential measures' socioeconomic and ecological impact. Threshold values trigger the drought indicators (e.g. if the flow rate of the Meuse at the Dutch municipality of Sint-Pieter reaches 60 m^3/s, the threshold for imminent water scarcity is indicated. Effective water scarcity is pointed at a 30 m^3/s flow rate.)

3.4 Spatial Policy Plan of Flanders

The strategic vision document of the Spatial Policy Plan of Flanders (Beleidsplan Ruimte Vlaanderen) includes a picture of the future image and an overview of long-term policy options, particularly the strategic objectives for future spatial development. The Spatial Policy Plan of Flanders sets out the Flemish Government's policy line to implement a renewed philosophy and approach to spatial policy (Departement Omgeving, 2018). It sets out key qualities for spatial development projects. Concerning drought mitigation, one of the mentioned key qualities is climate resilience. This key quality is reflected in the strategic objective where spatial designs or plans should reduce a location's specific climate sensitivity (heat stress, flood risk, etc.). Additionally, the strategic objectives aim for spatial design to contribute to climate-proofing by applying multifunctionality as a spatial development principle. The strategic vision document of Spatial Policy Plan Flanders (2018) refers to resilient, open spaces connected by a blue-green network as essential for water collection, infiltration, and storage. Consequently, this approach aims to simultaneously mitigate flood and drought events by soil infiltration enhancement in open, unbuilt areas and on a small scale in builtup areas. Additionally, the vision document states to limit additional soil sealing. In February 2022, the Flemish Government published the Draft Memo Construction Shift Action Plan (Conceptnota Bouwshift, Plan van Aanpak), where "the Flemish Government is working on a spatial transition and construction shift. The objective remains to reduce the additional land taken to 3 ha/day by 2025 and 0 ha/day by 2040" (Vlaamse Regering, 2022). The draft memo sets out legal and financial procedures. The Spatial Policy Plan of Flanders presents an overarching vision of interwovenness: a multifunctional approach to water management, food production, biodiversity, clean water, healthy air and recreation embedded into a qualitative landscape. In this approach, drought mitigation strategies embed into Flanders' broader vision of sustainable spatial development.

3.5 The Climate Adaptation Plans

The Flemish Climate Policy Plan 2021 – 2030 (2018) mentions drought only once. The plan's section on carbon capture in the agricultural sector notes that the large carbon capture capacity on farmland and pastures also encompasses the potential of improved soil quality and, therefore, resilience against drought and erosion. Climate Adaptation Plans are also developed at the provincial or municipal level. The Climate Adaptation Plan of the province of Antwerp lists different impacts and potential solutions to drought for its authorised region (Provinciaal Klimaatadaptatieplan, 2016). The effects of drought in the province of Antwerp range from biodiversity loss and natural degradation in natural and recreational areas, reducing drinking water availability to economic impacts on water-dependent sectors such as energy production, chemical industry and agriculture.

Additionally, the Antwerps Climate Adaptation Plan notes several already observed drought impacts, such as increased risks of forest fires, insect pests, agricultural losses, and reduced available food for pasture animals. Furthermore, the proposed climate adaptation strategies concerning drought coincide with the proposed development of green-blue structures in urban and outlying areas (buitengebied). Therefore, the strategy of the Climate Adaptation Plans of the province of Antwerp is complementary to the strategies of the Spatial Policy Plan of Flanders. However, the Climate Adaptation Plan sets out more concrete drought mitigating examples, such as implementing wadi and rainwater wells. Additionally, the Climate Adaptation Plan does suggest that Spatial Implementation Plans (RUPs) could be a spatial policy tool to implement these strategies. For example, the RUP Bedrijvensite ECA Tiestraat incorporated infiltration and water buffering measures to be implemented on the site. These measures were derived from the municipality's Climate Adaptation Plan (Meert et al., 2019). Additionally, the municipality of Eeklo also presents a drought measure containing facet in a Spatial Implementation Plan (Rup Galgenhof), which is still in development, by aiming to connect green woody linear structures in the city centre. (Meert et al., 2020). Examining all municipal Climate Adaptation and Spatial Implementation Plans in Flanders for drought mitigation strategies is not in the scope of this thesis. However, it could be expected that the significance of drought mitigation measures in these spatial planning tools will increase in the future. Furthermore, drought mitigation has especially gained importance on the spatial policy agenda due to the Bleu Deal.

3.6 Pilot projects of the Blue Deal and PROWATER

With the Blue Deal, the Flemish government presents 70 actions to structurally address water scarcity and drought in Flanders (Blue Deal - Integrale Tekst, 2020, Overleg Binnen de Droogtecommissie — Nl, n.d.). The Blue Deal aims for six different tracks: (1) the public sector shows good practices and provides the appropriate policy; (2) circular water usage becomes the rule; (3) agriculture and nature are a part of the solution; (4) stimulating rainwater infiltration in built-up areas; (5) increasing supply and (6) investing in innovations to aim for the water system to become smarter, robust and sustainable.

In the Blue Deal, an ecosystem-oriented approach is embraced for the first time (Jacobs et al., 2021) by aiming for a coherent and qualitative system of nature, forests and valleys (Blue Deal- Integrale Tekst, 2020). The "agriculture and nature are part of the solution, "stimulating rainwater infiltration in built-up areas" have a solid spatial planning component. Via the recovery plan 'Vlaamse Veerkracht' (Flemish Resilience), 343 million euros was budgeted for thirteen pilot projects of the Blue Deal. It concerns (terrain) realisations by the Flemish government and the financial support of initiatives by (agricultural) companies, local governments, sector organisations, knowledge institutions and associations. Currently, these pilot projects are in development, and spatial policy plans are not yet publicised (Blue Deal: Lokale Hefboomprojecten Gebiedsontwikkeling Met Focus Op Natte Natuur- Departement Omgeving, n.d.).

PROWATER is an EU research project between Flanders, The Netherlands and England, funded by the Interreg 2 Seas fund (EFRO) (Staes et al., 2020). The primary goal is to develop more climate-resilient landscapes by restoring the water storage with nature-based solutions and a participatory stakeholder approach. Therefore, different pilot projects are monitored and showcased to the public. These pilot project monitoring results will contribute to a 'Payment for Ecosystem Services' model (in development). The Payment for Ecosystem Services model's primary goal is to provide data to develop financial compensation mechanisms for actors that implement drought strategies. Additionally, the project aims to provide policy and water users information by developing water scarcity and drought risk long-term visions. In Flanders, several pilot projects are situated in the Campine region. Section 4.2.2.1.2 further elaborates on one of the pilot projects of PROWATER.

3.7 Spatial planning instruments that imply drought mitigation

“The planning system has a major part in the climate change policy agenda” (Davoudi, 2009, p. 2). Historically, spatial planning in Flanders had limited attention to climate adaptation, and mainly regulated land consumption and participated little in the debate on climate-related challenges (Bracke & van den Broeck, 2012). Climate research and spatial planning policy also have diverging characteristics: climate change research focuses on long-term and global trends, while spatial planning practices historically often focussed on short-term and local needs (de Waegemaeker et al., 2017). The following sections focus on spatial planning policy regarding drought mitigation.

3.7.2 River basin management plans on the Flemish policy level

On 24/09/2018, the Flemish Parliament stated in the September statement that the record dry summer of 2018 ‘confronted us with the reality of climate change’ (Septemberverklaring 2018, 2018) and referred to the implementation of a structural plan against drought and flooding. Thus, a decision was made to integrate a structural approach toward water scarcity and flooding into river basin management plans (RBMPs) (Actieplan Droogte En Wateroverlast 2019 - 2021, 2019). Additionally, the September statement of 2021 states that “the Flemish government invests hundreds of millions of euros in climate adaptation in order to be able to withstand the extremes of too much or too little water with more open space than ever. More green, more forests, more nature, more biodiversity and more sustainable agriculture” (SEPTEMBERVERKLARING 2021, 2021).

According to the definition of the Water Framework Directive, the area of Belgium covers four international river basin districts, which are shared with neighbouring countries (Bressers et al., 2016). The Scheldt and Meuse basin cover most of the territory of Belgium, which, next to the smaller Yser basin and Polders of Bruges in the west, encompass the region of Flanders. The Seine and Rhine river basins cover smaller parts in the south of Belgium. Except for the Federal Plan on Coastal Waters, water management plans in Belgium are organised and developed at the regional policy level (Bressers et al., 2016). As a result, river basin planning mainly has a regional approach.

The European Water Framework Directive, which aims to improve Europe’s water quality and quantity, translates into river basin management plans (RBMPs) on the national and regional policy levels (de Smet, 2021). The responsibility for developing RBMPs for two Flemish parts of the international river basin districts, Meuse and Scheldt, resides with the Flemish government (Bressers et al., 2016). The Coordination Committee on Integrated Water Policy (CIW; chaired by the Flemish Environmental Agency, VMM) is assigned to develop the RBMPs, including the groundwater specific and sub-basin parts. In addition, the CIW organises public consultation of the RBMPs, prepares the methodology and guidance for the development of the RBMPs and aligns the RBMPS with the Flemish Water Policy Note (see section 3.1).

These RBMPs contain actions and goals to improve water quality, lower susceptibility to floods and enhance resilience to drought. In 2016 River Basin Management Plans (RBMP) 2016-2021 was implemented (CIW, 2016a). Different water plans on the Flemish policy level and river basin specific policy plans were incorporated into the RBMP 2016 – 2021. The Flemish government adopted the 2016-2021 river basin management plans on 18/12/2015 and had already implemented flood risk management plans due to the European Flood Directive from 2007. The European Flood Directive demands special attention for spatial planning and land use (Departement Omgeving, 2018). On the other hand, a European drought management policy framework is currently less concretely developed (Actieplan Droogte En Wateroverlast 2019 - 2021, 2019).

The RBMPs 2016 – 2021 do present some actions to counter drought conditions. The RBMPs 2016 – 2021 (CIW, 2016b) mainly focus on improving water quality and managing excess water. By doing so, RBMPs 2016-2021 highlight the prevention and reduction of permeable surfaces regarding reducing surface runoff. The RBMPs 2016 – 2021 also state that these measures counter drought by enhancing infiltration. "The imposed measures will be implemented through spatial planning policy or the measures of the environmental permit decree (milieuvergunningendecreet). Measures can be included in the environmental permit" (CIW, 2016b). The same enforcement instruments presented in the environmental permit procedure can also cover drought mitigating measures. "A coherent approach in water management, in general, can be seen in the synchronisation of the planning period of (sub-) basin RBMPs. Also, integration of drought measures in the RBMPS shows a tendency to a harmonised approach of developing and implementing drought measures with other water management measures" (Bressers et al., 2016, p. 151).

CIW (2016) states that the effect of climate change on groundwater supply is little known. However, aspects such as quantity and periodicity of precipitation, (an increasing amount of) paved surfaces, policy around water infiltration and the influence of nature conservation goals play a very significant role in the supply and flow towards groundwater. A separate section, the Groundwater System Specific Section of the RBMPs (grondwatersysteemspecifieke delen) is dedicated to the six groundwater systems in Flanders, each with a policy component with specific actions for each groundwater system. In areas where the quantity of groundwater is insufficient, restoration programs need to be implemented to balance the demand and supply of groundwater. For example, several groundwater bodies are indicated as quantitively inadequate in the northeastern part of the province of East-Flanders and the western part of Antwerp. Proposed actions by CIW (2016) suggest that the negative groundwater quantity trend needs to stop and that the demand for (ground)water should be levelled towards the supply of (ground)water. With this in mind, CIW (2016) formulates policy proposals such as reducing licensed groundwater extraction, fiscal policy to stimulate sustainable water usage and management and tri-annual trend assessments to monitor groundwater levels. CIW (2016b) states in the RBMPs 2016 – 2021 that next to a licensing and tariffs policy, the illegal extraction of groundwater should also be addressed through database water usage analysis, terrain signalisation and licensed drill operators. Additionally, Jacobs et al. (2021) argue that in order to improve groundwater quantity, groundwater extraction licenses should be re-examined.

The RBMPs 2016 – 2021 also highlight the importance of municipalities to ensure that groundwater drainage at a construction site that is discharged into the sewerage system should be notified to the municipal government so that the municipality could evaluate if the construction site drainage water could preferably be released at an area where the water could infiltrate into the soil (CIW, 2016b).

The proposed actions and vision in the Blue Deal, the Climate Adaptation Plan 2021- 2030 and Spatial Policy Plan Flanders to combat drought and water scarcity could be canalised into a River Basin Management Plans (Jacobs et al., 2021). However, Jacobs et al. (2021) argue that the promises made in the Blue Deal were not sufficiently translated into the preliminary design drafts of the River Basin Management Plans 2022 – 2027. Moreover, the RBMP’s 2022 – 2027 are primarily focused on improving water quality instead of water infiltration strategies to increase the groundwater supply. Therefore Jacobs et al. (2021) argue that the Flemish water authorities should incorporate the actions of the Blue Deal into spatial plans to a much greater extent. However, Minister Demir stated that she would align the RBMPs with the Blue Deal after the public survey of the RBMP’s 2022 – 2027 is completed. Bresser et al. (2016) also state that “there are as yet not many actions that address droughts at the Flanders [policy] level. There seems to be a ‘culture of coordination’ within the authorities dealing with water topics” (Bresser et al., 2016, p. 150). On the other hand, Bressers et al. (2016) state a negative trend in which municipalities disengage from water management responsibilities.

> “For instance, in their [municipalities] limited degree of responsibility of “type 3” [small] watercourses, which is handed over to the provinces. This could mean that municipalities end up ‘out of the loop’ regarding, for example, water quality and nature protection, and thus may be unaware of opportunities for synergies related to water management, such as drought preparedness. This is problematic as spatial planning keeps much potential for implementing flood measures and measures to implement drought prevention while also addressing flood risk with municipalities. This is also relevant when considering that towns and municipalities grant groundwater permits.” (Bressers et al., 2016, p. 5)

Local of regional governments can implement drought mitigating measures with Spatial Implementation Plans and rainwater and drought plans (section 3.7.3).

The public survey regarding the development of the RBMPs 2022 – 2027 finished on 14/03/2022. The results can be expected later in the year 2022. The several draft versions of the RBMPs 2022 – 2027 propose drought mitigation strategies. For example, the draft RBMP Klein Nete suggests storing, retaining, and delaying water discharge in the upper basin region to mitigate drought impacts by restoring biodiversity, remeandering and rewetting land parallel to the Kleine Nete valley system (CIW, 2020). Unfortunately, the finalized RBMPs 2022 – 2027 will not be available in the time frame of this thesis for further research.

3.7.3 Rainwater and drought plans

In recent years, the growing sense of urgency to take a different approach to rainwater has gained traction (Wieme, 2021). As a result, the scope of rainwater plans in the Flemish vision rapport Blue Deal has been broadened to rainwater and drought plans (Blue Deal - Integrale Tekst, 2020). A rain plan is primarily focused on discharging excess precipitation to counter flood events. A rainwater and drought plan provides an integral vision for an area on how to infiltrate, re-use and buffer as much water as possible and, as the last step, delay the discharge to the lower laying basin (Wieme, 2021; Hemelwater- En Droogteplan - VLARIO, n.d.). The Blue Deal incentivises municipalities to develop these plans by 2024 by only providing access to water-related subsidies if they have ambitious rainwater and drought plans (Blue Deal - Integrale Tekst, 2020; Wieme, 2021). The CIW (CIW, 2021b) provides a blueprint for municipalities to develop such plans. The blueprint clarifies the content of rainwater and drought plans, the process which needs to be followed for its preparation and approval, and the consequences for local policy and initiatives in the field (Wieme, 2021). The blueprint also provides lists of good practices for rainwater and drought management.

The blueprint was developed within the Project Group Rainwater and Drought Plans of CIW with the collaboration of several other stakeholders[1] (CIW, n.d.). The main goal was to develop a similar approach between municipalities towards drought and flooding by providing a functional framework so that local policymakers and partners can make planning decisions that can contribute to a climate robust water system (CIW, n.d.). The plan highlights some opportunities and bottlenecks for an area to tackle flooding and water scarcity. A win-win approach is intended towards climate adaptation, environmental quality, biodiversity, circular water usage and implementation of blue-green networks. A rainwater and drought plan intends for municipalities to be more resilient towards climate change and potentially provide solutions for biodiversity loss and the heat-island effect (CIW, n.d.). The plan aims to retain as much rainwater and delay and slow down the discharge rate as much as possible to maximise the input towards groundwater (Opmaak Hemelwater-En Droogteplan-Blauwdruk, 2021). The blueprint highlights minimal use of impermeable surfaces and maximises infiltration and buffer facilities, preferably with natural green land cover and multiple land-use functions. This combination can provide ecosystem services next to water infiltration, such as combatting the urban heat island effect and improving carbon storage. The policy text of the blueprint for municipalities to develop rainwater and drought plans underlines the integral vision of the planning approach. CIW (n.d.) states that this planning approach to water policy can be combined with principles of the Spatial Policy Plan Flanders of increasing spatial efficiency and improving/extending open spaces.

1 Vereniging van de Vlaamse Provincies (initiator of the project), Vereniging van Vlaamse Steden en Gemeenten, Vereniging van Vlaamse Polders en Wateringen, De Vlaamse Waterweg, Vlaamse Milieumaatschappij, Agentschap voor Natuur en Bos, Agentschap Wegen en Verkeer, Aquaflanders, Aquafin, Departement Landbouw en Visserij, Depar tement Omgeving, Vlario, University of Antwerp, University of Leuven (Sumaqua) and 14 local authorities.

3.7.3.1 Current rainwater plans

Since 2013, the Flemish government has recommended that municipalities develop rainwater plans (Blue Deal- Integrale Tekst, 2020). Since 2019, 31 municipalities have developed a basic rainwater plan for at least a part of the municipality's area (map 11). Seven municipalities developed a detailed rainwater plan (map 11).

A detailed rainwater plan's primary focus is managing flood risks. These plans incorporate drought mitigation measures as part of a flood risk-reducing strategy. The municipality of Lichtervelde, Moorslede (West – Flanders) and Brasschaat (Province of Antwerp) do present drought mitigation measures in their rainwater plan. A comparative scheme (figure 3) sets out two drought measures found in each municipal plan: reducing soil sealing and increasing the rainwater buffer area.

The effects of soil sealing reduction on drought mitigation for the rainwater plans of the municipalities Brasschaat, Lichtervelde and Moorslede are assumably insignificant (less than 1% soil sealing reduction after implementation). However, this thesis will not elaborate further on this hypothesis. Consequently, no definitive statements can be presented in the case of these municipalities. Additionally, the effect of reducing soil sealing on drought mitigation is not a primary strategy to reduce drought risks suggested by researchers such as de Waegemaeker et al. (2017), de Sutter et al. (2012) and Foré et al. (2012) (see section 4.3.1). The rainwater and drought plans in figure 3 present an average increase of 60% in rainwater buffer area. Therefore, if implemented, these measures could potentially significantly impact the municipalities' drought mitigating strategies.

Several municipalities such as Brasschaat, Ingelmunster, Koekelare, Kapellen and Diksmuide are developing rainwater and drought plans. The scope of this thesis will not further elaborate on these rainwater and drought plans as they are currently in a development phase for most municipalities. However, comparative research or process analysis of these plans could provide interesting future research opportunities.

3.7.4 Drought mitigation measures on the individual plot

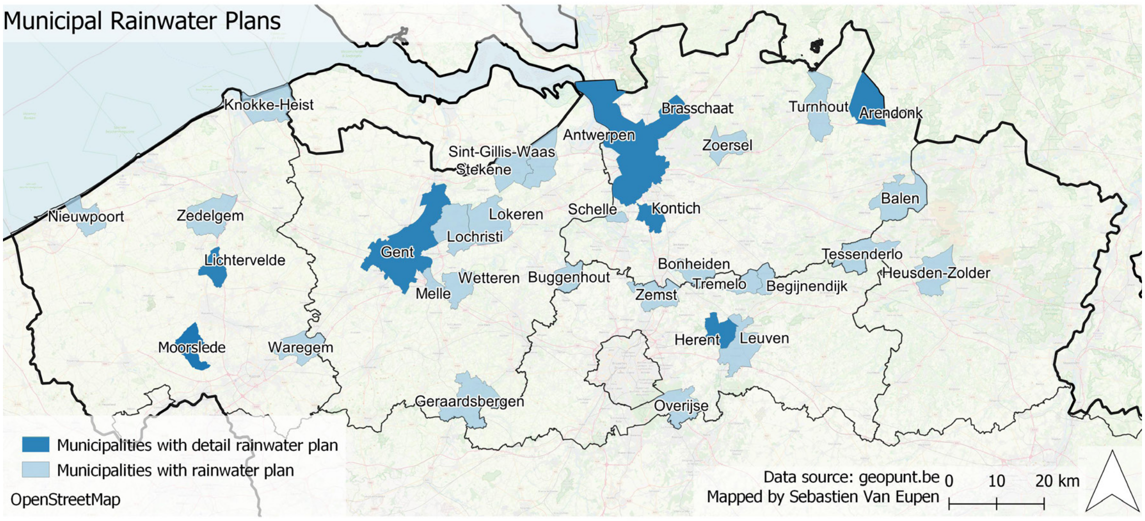
Since 29/09/2016, a Regional Planning Regulation (***Stedenbouwkundige Verordening***) states that new construction or sealed soil areas over 250m² should facilitate infiltration and rainwater-buffering capacities, rainwater wells and separate rainwater from wastewater (CIW, 2016c). This Planning Regulation is integrated into the permit application process. Additionally, the Blue Deal (Blue Deal - Integrale Tekst, 2020) states that "applying for a permit for a new building or a thorough renovation, a water scan is obligatory, to maximise the potential for sustainable water use. We are examining whether this should remain a separate scan or can be integrated into other instruments in the planning of the building process" (p. 20).

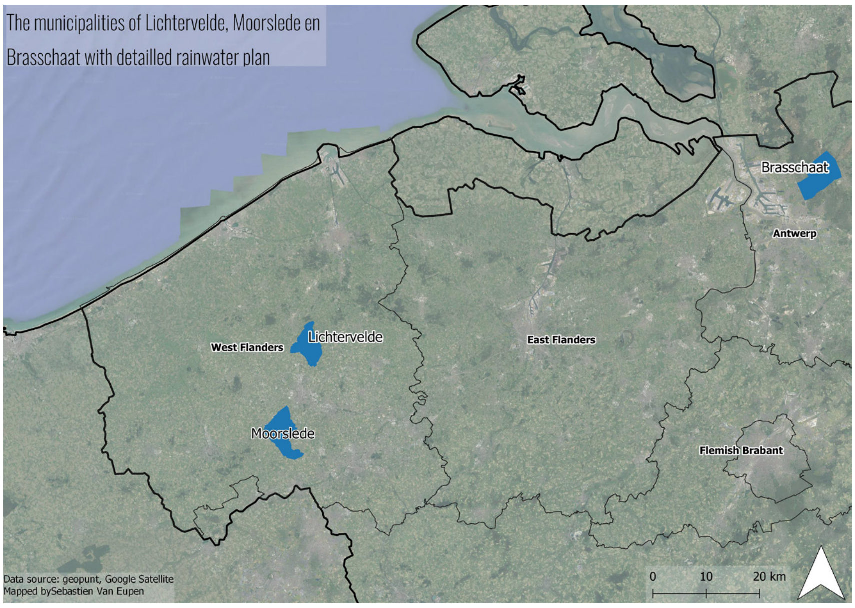
Furthermore, water scans (Waterscan | Waterportaal, n.d.) or the Water Barometer, developed by VITO (van Ermen, n.d.), provide companies and individual households insights into their water demand and strategies on how to increase their water use efficiency.

Map 11: Municipalities with (detailled) rainwater plan

Mapped by Sebastien Van Eupen

Data source: geopunt.be, OpenStreet-Map.





Two drought measures in the detailled rainwater plans of the municipalities of Brasschaat, Moorslede and Lichtervelde

- Soil sealing reduction
- Increased rainwater buffer area

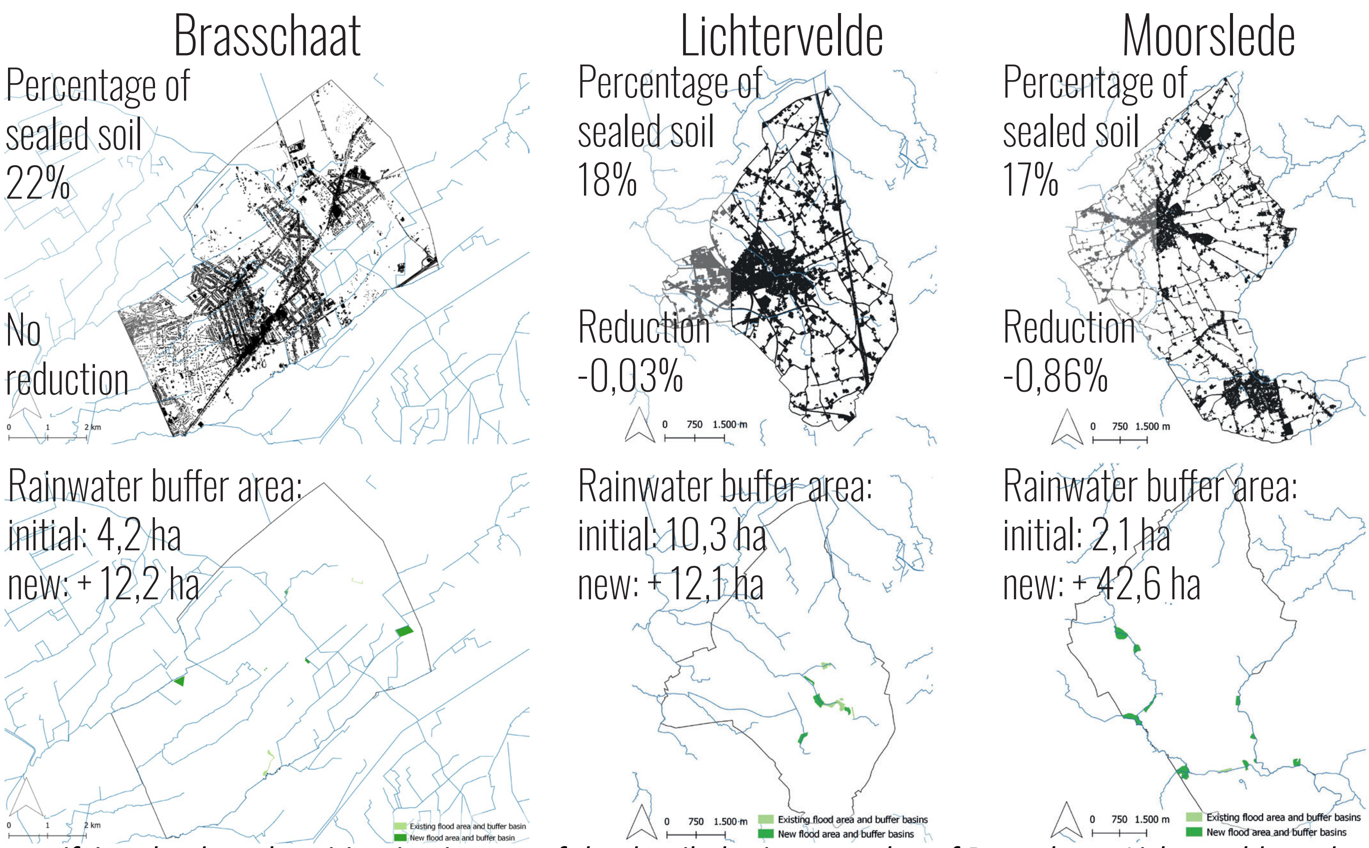


Figure 3: Quantifying the drought mitigating impact of the detailed rainwater plan of Brasschaat, Lichtervelde and Moorslede, mapped by Sebastien Van Eupen, data source: geopunt.be, Google Satellite Imagery

3.8 An overview of Flanders' drought policy

"A [drought] policy [in Flanders] is still in its infancy, especially for drought risk management" (Actieplan Droogte En Wateroverlast 2019 - 2021, 2019, p. 6). In contrast to flood damage, Northern and Western European member states were not frequently confronted with drought events (Tabari et al., 2015; KMI, 2020). In 2007, the European Commission's Flood Directive provided a policy framework. This directive requires adequate monitoring and developing objectives and measures through risk management. However, there is currently less of an EU policy framework for drought management (Actieplan Droogte En Wateroverlast 2019 - 2021, 2019; Raikes et al., 2019). Still, the risk approach of flood management potentially provides a basis for Flanders' policy framework for drought management. Flood risk assessments draw several principles from a multi-layered water security approach. These principles present a subdivision of three different approaches towards drought policy (Raikes et al., 2019).

(1) Protective measures: limiting the chance of flood/drought occurrence. Actions that retain, store, and enhance water infiltration are classical protective measures for floods and droughts. Birch (2019) states that cities and municipalities are key players at the frontline of these kinds of adaptation measures.

(2) Preventive measures: limiting flood/drought-related impacts. These actions can be situated into the spatial permit policy for flood/drought-prone areas. In addition, water conservation awareness-raising, cultivation choices, and optimisation methods of industrial processes are also categorised as preventive measures.

(3) Preparedness enhancement: limiting flood/drought damage with crisis management and awareness-raising in addition to efficient and equitable remediation measures in case of a flood/drought event. Indication and forecasting systems are crucial in this case.

The protective and preventive measures are designed to prevent disasters and mitigate potential impacts (Raikes et al., 2019). These measures enhance a community's resilience to drought events. These approaches shift away from a more reactionary flood/drought management model related to crisis management. Raikes et al. (2019) state that proactive protective and preventive measures do not eliminate the use of crisis management by governments. Thus, all three drought approaches prove to be valid. Additionally, this prevention-protection-preparedness framework toward natural hazards has also been set out by Khan et al. (2003). Similar approaches were presented by Lu & Stead (2013) by describing a system's robustness by its "strength to carry and absorb uncertain disturbances" and its flexibility to "rearrange itself into a new stable state after a collapse occurs" (p. 3). For example, a city's resilience translates into preparation for a potential flood/drought. This is reflected in the administration's flood/drought risk management (cf. preparedness) and the absence of construction rights or adapted building typologies in vulnerable areas in the case of flood risk management (cf. preventive measures).

Section 4 of this master thesis, focuses on protective measures for drought policies in Flanders. Nonetheless, the drought policy set out in the previous sections will be outlined in figure 4 and presents an overview of the drought policy landscape in Flanders and to subdivide different policies according to a protective, preventive and preparedness approach.

The Flemish Water Policy Note, Decree on Integrated Water Policy and, to an extent, Climate Adaptation Plans form a basis for drought policy in Flanders. Although, examination of the Flemish Water

Policy Note and Decree on Integrated Water Policy primarily suggests a primary focus on managing flood risks and drought impacts to a lesser extent.
Rainwater and drought plans, the PROWATER's and Blue Deal's pilot projects, and objectives of reducing soil sealing and stimulating water infiltration in the Spatial Policy Plan Flanders present characteristics of a protective policy approach towards drought mitigation (figure 4, p. 39). The policy's implementation would enhance rainwater infiltration, retention and storage and thus contribute to drought mitigation in Flanders.
The RBMPs present protective and preventive drought policy approaches. The river valley meandering and biodiversity restoration project proposals of the RBMPs can be characterized as a protective drought strategy approach. RBMPs also present policy suggestions such as reducing groundwater extraction licences and sustainable water usage. Therefore RBMPs additionally present preventive drought mitigation approaches. Additionally, the development of the rainwater and drought plans could potentially present a significant contribution to future drought strategy implementations via RUPs. Municipalities, such as Brasschaat, mentioned that these plans are currently being developed (10/05/2022).

The Assessment Framework for Priority Water Use and the drought indicators of the CIW present a reactive framework when drought occurs. These instruments lean towards a preparedness policy approach.

Notably, most of the mentioned drought policies in the previous sections have been developed in the last five years. This could indicate an increasing sense of urgency concerning drought in Flanders. Furthermore, the recent enrollment of the rainwater and drought plans and their impact on implementing drought mitigation strategies in Flanders can be expected to be very significant in future drought planning in Flanders. Therefore, the effects of rainwater and drought plans on effective drought mitigation could provide potentially interesting future research topics.

The first research question (section 1.4.1) posed if Flanders' drought policy leans toward a protective, preventive or preparedness approach. Figure 4 (p. 39) illustrates that all three approaches are present in Flanders' drought policy. The effectiveness of the drought preparedness approach policy was not examined in the scope of this thesis. Still, reactive policy instruments, such as the drought indicator assessments by the CIW and Assessment Framework for Priority Water Use, prove useful in managing drought events.

Subdividing drought policy approaches as protective and preventive proved to be challenging. Different protective policies provide a framework or a basis for actual drought mitigation measures implemented in the field or act as a pilot project for future drought policy development. On the other hand, preventive drought policy is mainly situated in the permit application process, which is based on Spatial Implementation Plans (RUPs) and Planning Regulations (*stedenbouwkundige verordeningen*). Therefore, the effectiveness of protective drought policy reports will depend on whether the proposed drought mitigation measures will be sufficiently implemented in Spatial Implementation Plans and Planning Regulations.

Kris Cauwenberghs (as cited in Torfs & Dumarey, 2022), notes that

> "Internationally, it has been recognised for some time that it is necessary to make the step from the current 'incremental' adaptation (cf. numerous pilot and demo projects) to a transformative adaptation, in which the urban environment is redesigned in a more extensive green-blue manner, but also the rural environment becomes more resilient to weather extremes that will not only continue to occur more intensely but also more frequently in the coming decades" (p. 1).

Arguably, this 'incremental' adaptation approach still underlines the protective drought policy in Flanders (figure 4) regarding the pilot projects. However, drought and rainwater plans and RBMPs 2022- 2027 could potentially stimulate extensive transformative adaption. The RBMPs 2022 – 2027 propose a (sub-) basin-level approach to retain, store and delay water discharge in contrast to the RBMPs 2016 – 2021, which prove to be less sufficient for implementing drought mitigation measures (Bressers et al., 2016; Jacobs et al., 2021).

Cauwenberghs' quote (2022) illustrates the long road that still has to be taken to transform Flanders into a drought-resilient region. Additionally, governance needs to continue and intensify the shift towards a more protective and preventive approach and connect different actors, stakeholders and sectors to focus on making drought resilience mainstream in all spatial planning-level decision makings (Bush & Doyon, 2019). Reconciling various stakeholders with different visions and spatial demands in the urban sprawled Flanders will be challenging when implementing drought mitigating strategies. Section 4 elaborates on this by examing the Kleine Nete river basin case.

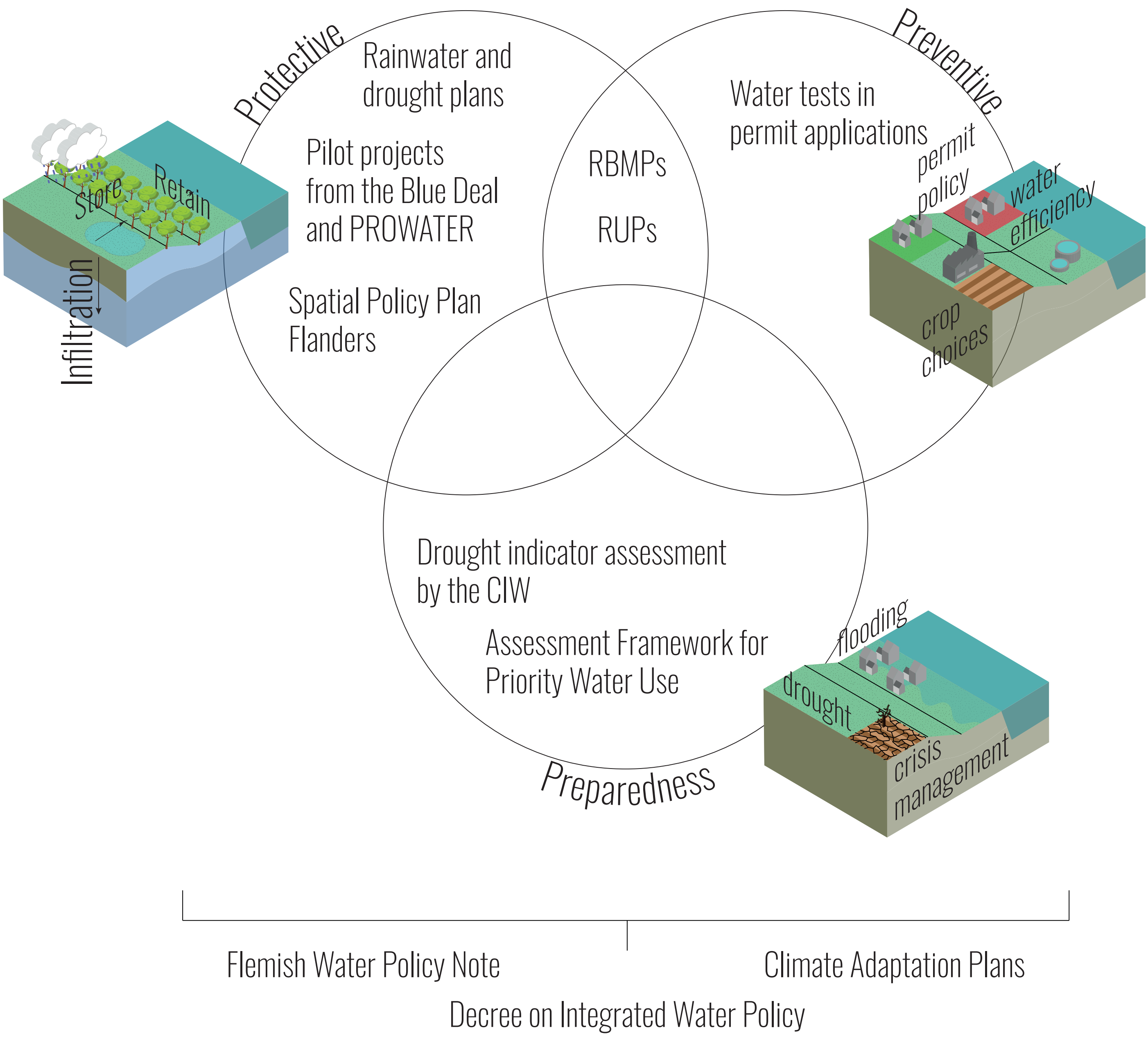


Figure 4: Subdivition of Flemish drought policy according to a protective, preventive or preparedness approach, Illustration developed by Sebastien Van Eupen

4. INCREASING DROUGHT RESILIENCE IN THE NETE BASIN

Solh & van Ginkel (2014) state that a drought event cannot be prevented, but interventions can be made to reduce its impact by improving drought resilience, resulting in better preparation to cope with drought and enhance ecosystem recovery from drought. Holling (1973) was the first to define resilience as the stability and ability of ecological systems to return to an equilibrium state after perturbations. The return time to the steady-state equilibrium following the perturbation determines the system's resilience. Resilience is thus a characteristic of a system that expresses its elasticity where a system returns to a particular comfort zone (Gullinck et al., 2012). This comfort zone can be expressed by a climate (and precipitation) average.

Figure 5 presents different future climate change systems (Verhofstede et al., 2012). The graph on the left illustrates a shift in the average distribution of the impacts on the x-axis. E.g. if the yearly amount of precipitation increases, the curve shift to the right (from a to a'). The curve shifts to the left if yearly precipitation decreases and to the right if yearly rainfall increases. In this scenario, societies' comfort zone shall have to be adjusted. For example, agricultural practices would have to adapt to drier or wetter conditions.

The second scenario on the right graph (figure 5) indicates that the average climate impact stays the same, but the standard deviation increases resulting in more extremes and less predictability (from curve a to a") (Verhofstede et al., 2012). In the example of precipitation, a society shall have to adapt to extreme precipitation events and intense, long periods of drought. Tabari et al. (2015) already mentioned in section 1 that "in Belgium, the wet season will get wetter and dry season drier, resulting in an increased risk of summer droughts and winter floods", indicating that future spatial drought policy shall have to consider the second scenario to improve Flanders drought resilience. Therefore, spatial planning strategies must create buffers for dry and wet periods (Verhofstede et al., 2012) to increase Flanders' resilience. Meerow et al. (2016, p. 1) define "urban resilience as the ability of an urban system and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales to maintain or rapidly return to desired functions in the face of a disturbance, to adapt, to change, and to quickly transform systems that limit current or future adaptive capacity". In urban planning, improving urban resilience refers to building a city or a community that would physically withstand external (climate change) shocks or disturbances.

Concerning drought mitigation strategies, this section considers a river basin as a hydrological planning unit, subdivided into smaller watershed units for management. The same planning approach has been highlighted by Schep (2020) concerning climate robust water system planning strategies in The Netherlands. This focus on a river basin approach indicates an integral system analysis of the water system. This physical landscape approach can potentially present nature-based solutions to increase drought (and flood) resilience. "This integrated approach is a task for spatial planners" (Schep, 2020) and requires planning strategies at local, regional, national and international levels. At the local level, spatial planning has a critical role in deploying climate robust adaptation strategies (Wilson, 2006). In order to engage local actors in adaptation strategies, a win-win approach to spatial adaptation is needed (Dewaelheyns & de Waegemaeker, 2012). Additionally, paying attention to aquifer recharge and flood plains is also a step forward in urban resilience (Hoa & Vinh, 2018).

Section 1.3 indicated that the Campine region in the eastern part of Flanders is especially susceptible to drought (map 12) map due to a sandy soil texture,

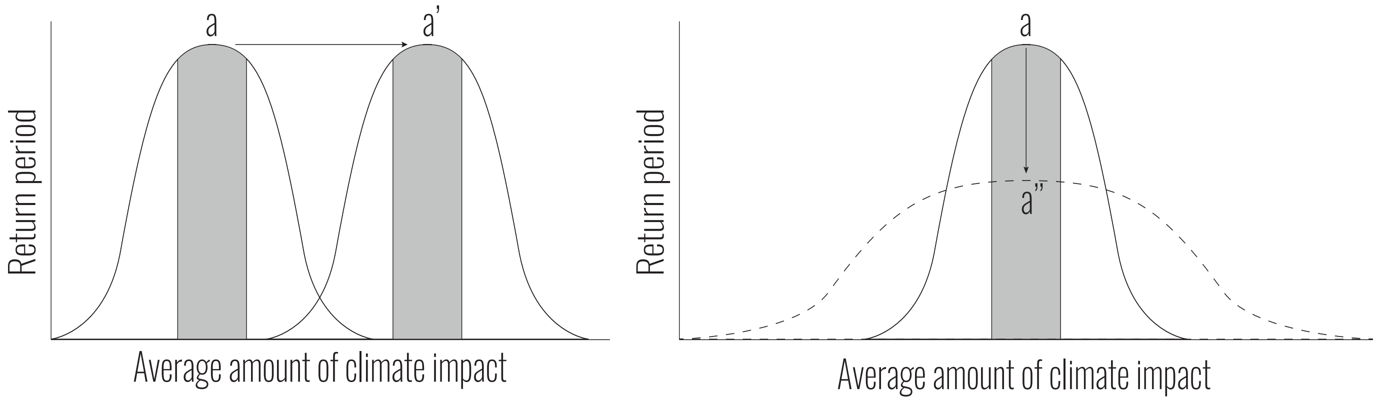
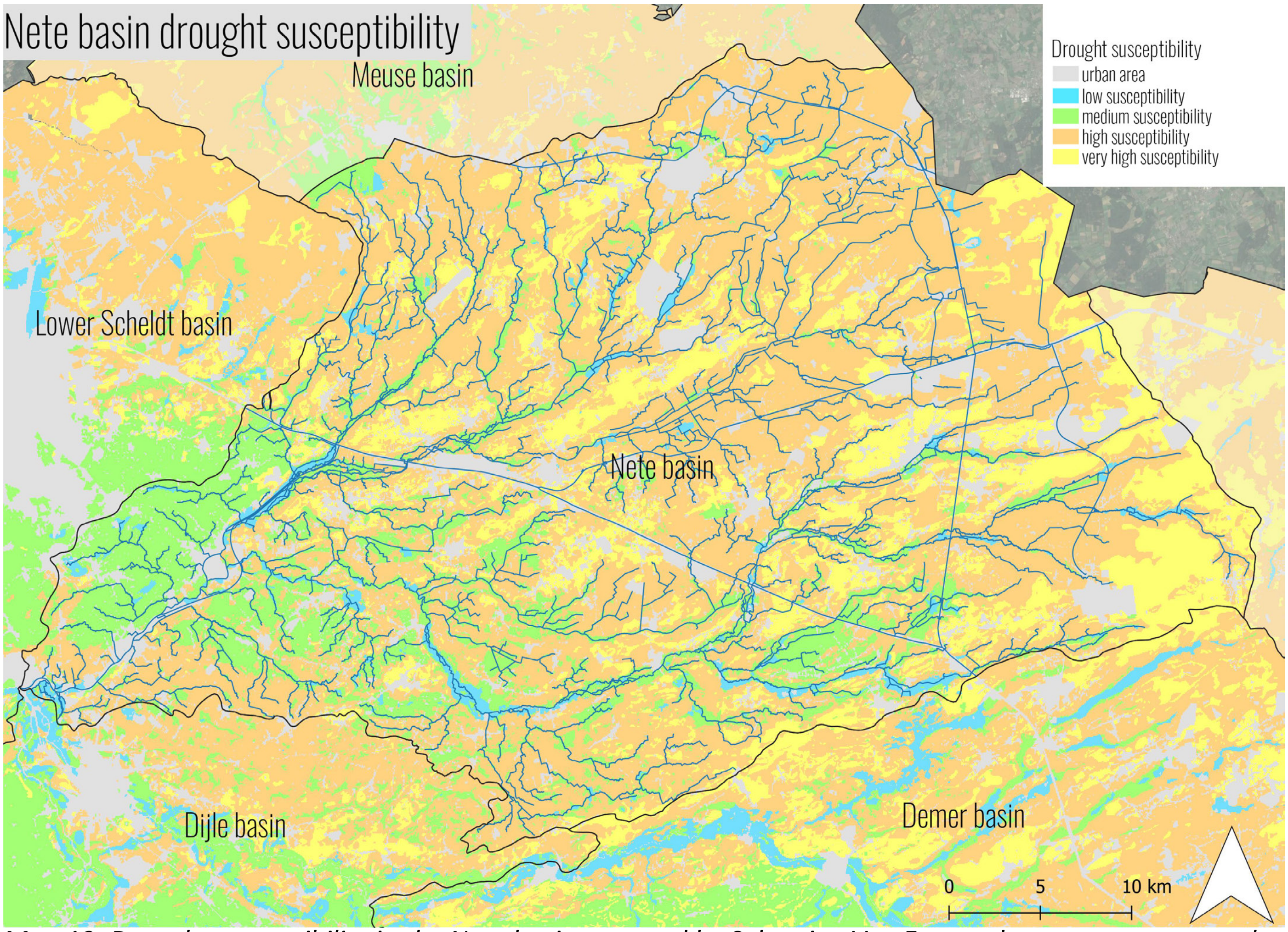


Figure 5 Variation and extremes with (1) a change of average amount and (2) a change in variation, illustration extracted from Verhofstede et al. (2012) and modified by Sebastien Van Eupen



Map 12: Drought susceptibility in the Nete basin, mapped by Sebastien Van Eupen, data source: geopunt.be

which has a relatively low capacity to retain water in the soil (map 9, p. 17). In addition, the eastern part of the Campine region also presents a gentle hilly relief (map 14, section 4.1), contributing to the region's drought susceptibility. Therefore the Nete basin in the Campine region shall be examined as a case study in this thesis. Firstly, the spatial context of the Nete basin shall be set out in section 4.1.1. Next, existing spatial (drought) planning in the Campine region shall be examined in section 4.1.2. Finally, section 4.2 outlines different spatial site-specific strategies to mitigate drought for specific areas in the Kleine Nete river basin.

4.1 Spatial context of the Nete basin

Section 1.2.1 already mentions the importance of the Campine and Nete water system. Flanders' water extraction extensively relies on Campine groundwater and water flowing through the Campine canals. Of the total licensed flow of drinking water extraction, 43% is extracted from the Campine aquifer system (Dewaelheyns & Foré, 2012). However, since 2016, a significant amount of groundwater levels have remained very low, too low for an extended period. Additionally, periods of groundwater recovery shortened over time (CIW, 2021a). This trend negatively impacts biodiversity, the water supply for the base flow of the Nete rivers, drinking water supply, and agricultural productivity in an area with significant water demand for drinking water extraction, industry and recreation.

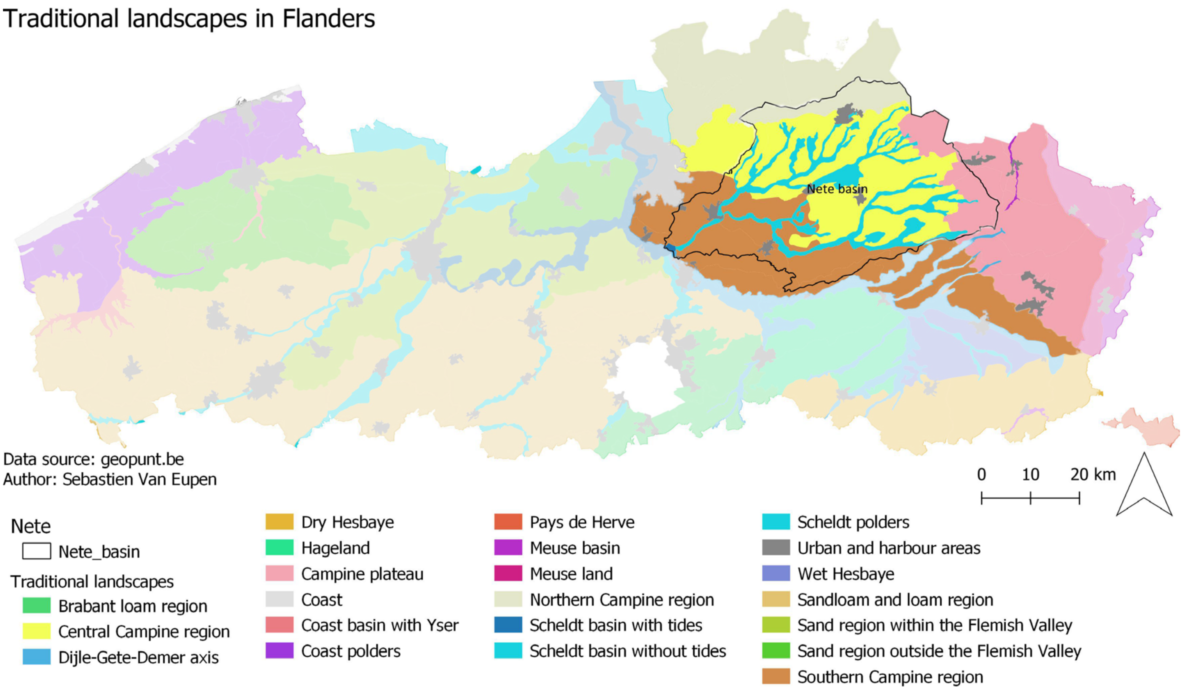
The Campine region has a strong cultural identity in Flanders (Dewaelheyns & de Waegemaeker, 2012). Coniferous forests and heathland remnants, contrasting areas of large industrial sites, more rural, fine-meshed landscapes with more minor landscape elements and open extensive agricultural farmland define the region's cultural identity. Dewaelheyns & de Waegemaeker (2012) state that climate and drought adaptation strategies must consider this collective cultural image of the Campine region to develop an "integral climate robust regional vision" (p.102). The increased risk of flooding and decreasing groundwater recharge indicate the need for spatial planning in the Campine region that takes the water system as an initial starting point. This would require "radical changes to the Campine landscape" (Dewaelheyns & Foré, 2012, p. 103). Therefore, the search for a compromise between maximum water system functionality and landscape transformation concerning regional and local identity is a significant challenge (Dewaelheyns & Foré, 2012).

4.1.1 Situating the Nete basin in the Campine region

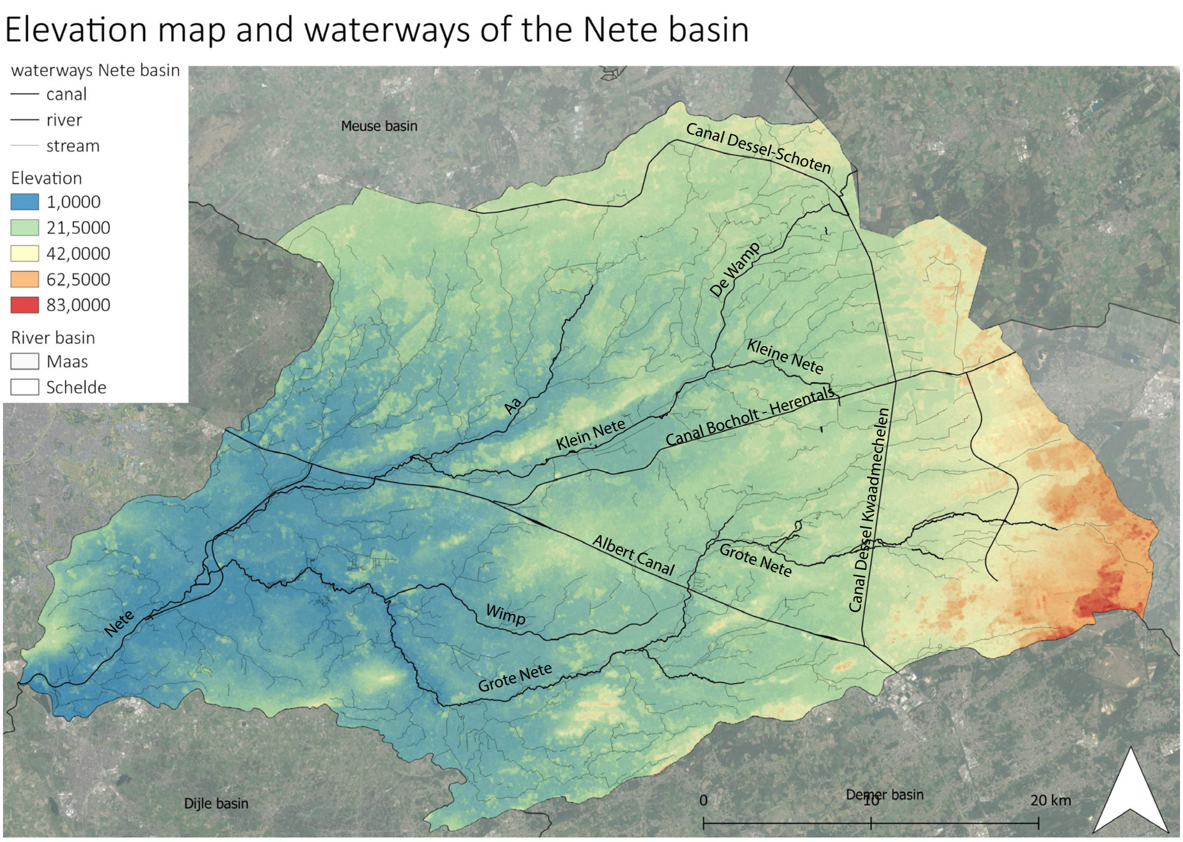
Map 13 presents the traditional landscapes of Flanders with the delineation of the Nete river basin, which is the focus of this master thesis. The Campine region subdivides into the Southern Campine region, the Northern Campine region, the Central Campine region and the Campine plateau in the east. This thesis focuses on the Nete basin and shall, therefore, primarily present relevant data at the level of the Nete basin (map 14).

Map 14 presents the elevation map and river systems of the Nete basin. Different river systems flow westward towards the lower-lying Campine plain towards the Scheldt river from the Campine Plateau. This western lower-lying area has a groundwater table situated relatively close to the surface (Dewaelheyns et al., 2012). The northern part of the Nete basin characterizes by an open agricultural, relatively flat landscape (Open Landschap Noorderkempen Landschapsbeeld Biodiversiteit, 2015). In contrast, the southern region of the Nete basin, situated in the Southern Campine region, is structured by the two Nete rivers: the Grote Nete and Kleine Nete. These two rivers flow more or less parallel from east to west (map 14). Historically, areas along these rivers are characterized as wetlands due to surfacing groundwater and fluvial flooding. The higher-lying

Map 13: traditional landscapes of Flanders, data source: geopunt.be, mapped by Sebastien Van Eupen



Map 14: river systems and elevation map of the Nete basin, data source: geopunt.be, mapped by Sebastien Van eupen



areas and sand ridges between the rivers act as infiltration areas (Dewaelheyns et al., 2012).

4.1.2 A brief overview of the historical and current landscape forming and planning actors and policy in the Nete basin

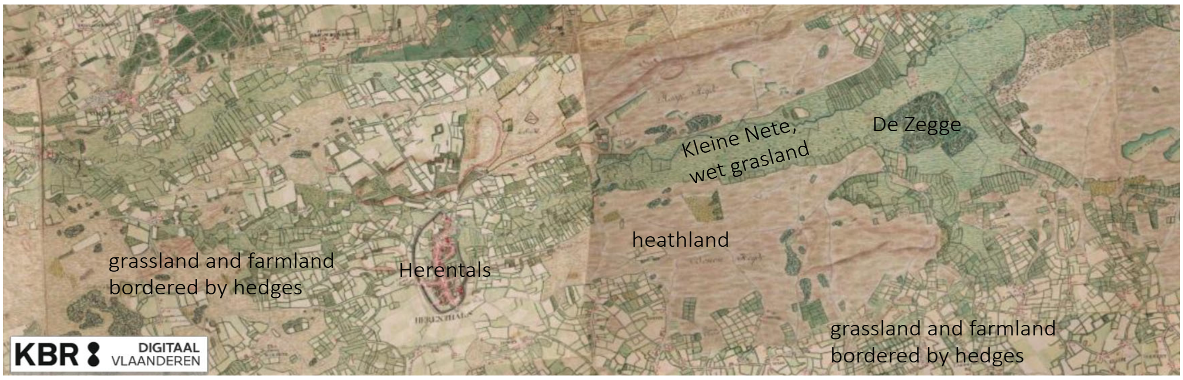
The history of the Campine region characterizes by constant landscape adaptation to new circumstances due to policy changes and economic dynamics in industry, agriculture and forestry, under the influence of an ever-increasing group of actors (Dewaelheyns et al., 2012). Pre-1850 forests converted into heathland due to extensive overgrazing, the agricultural practice of removing topsoil layers (Dutch: "***plaggen"***) and wood chipping. As a result, the landscape differentiates between heathland, villages, valleys, and bocage landscapes (grassland parcels bordered by hedge structures, Dutch: "***beemden"***) (map 15).

The Campine landscape has drastically changed during the 19th and 20th centuries due to the privatisation of commons, straightening and diking the Nete rivers, constructing different canals to facilitate industrial activities, and providing irrigation water for farm parcels. However, the intended irrigation capacity of the latter was not sufficient (Van Acker, 2010).

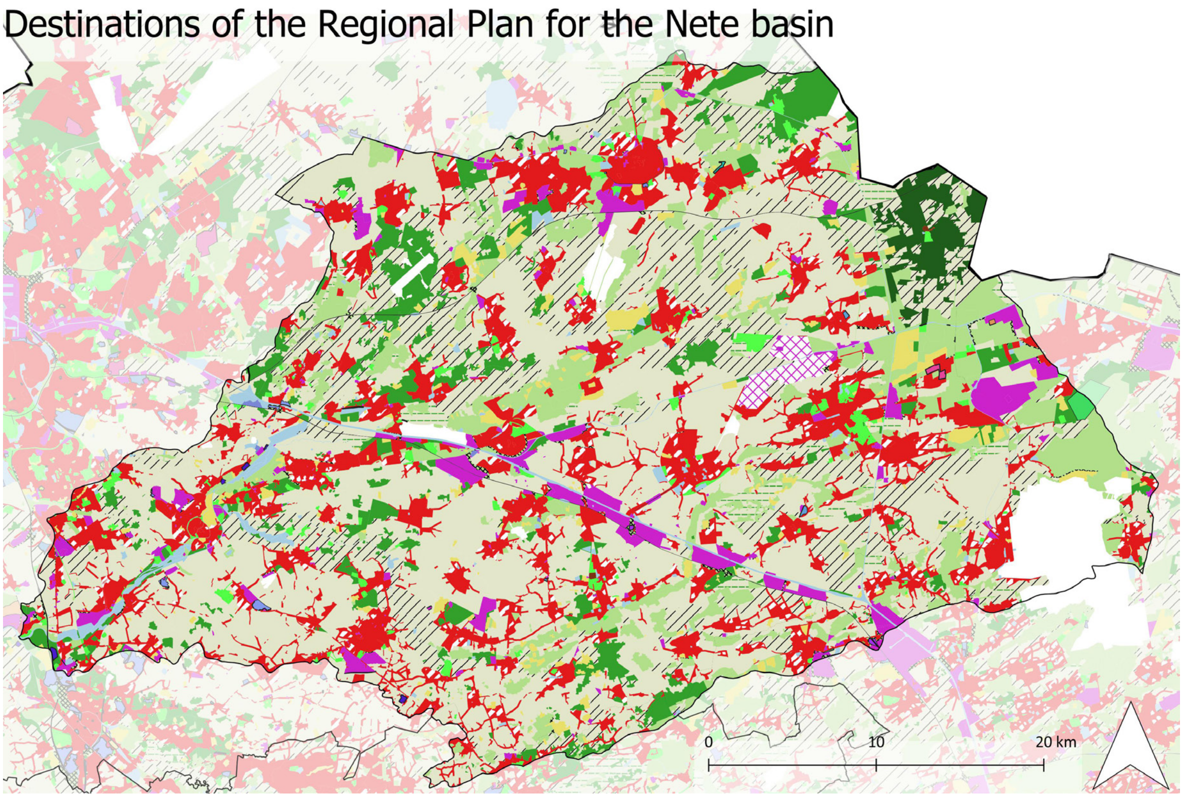
The second half of the 20th century characterizes by a large-scale restructuring of the landscape (Dewaelheyns et al., 2012). Large infrastructure projects such as the E313-highway and the Albert Canal, the declining demand for hay and wood and a spatial policy focused on an industrial growth discourse profoundly changed landscapes in the Nete basin (Van den Broeck, 2012, cited in Dewaelheyns et al., 2012). Agriculture was also subject to modernisation and mechanisation. In this trend, land consolidation projects in the 1960s resulted in the drainage of the groundwater dependant peatland, significantly reducing the water buffering capacity of the Kleine Nete (Dewaelheyns et al., 2012). As a result, whole peat bog areas along the valley system were drained, parcelled, and developed for agricultural purposes, except for the nature area of De Zegge (Verhoestraete & Staes, 2019). The case of De Zegge shall be thoroughly elaborated on in section 4.2.2.2.

Due to increasing automobility and the construction of highways and other policy drivers, the green Campine area became an attractive residential area, resulting in high residential pressure on open space. For example, from the 1960s onwards, landowners and developers used the possibilities offered by the Town Planning Act of 1962 (Dutch: "Wet op de Stedenbouw van 1962") to apply for allotment permits. Consequently, much land was being parcelled out on the outskirts of village centres in this period, and ribbon development along connecting roads increased. Hence, from the 1960s onwards, landowners appropriated more and more land for private use, such as housing, and recreation. In addition, even after the Regional Zoning Plan of Geel-Mol was approved, local authorities leniently handled permit requests for large development plans (Dewaelheyns et al., 2012). However, the area's planning destinations are dominated by agriculture, covering almost 50% (32,9% + 15,5% + 1,4%) of the basins area (map 16 and figure 6).

From the 1990s, demand for more nature development and ecological networks translated into policy measures, such as the Groene Hoofdstructuur: a map used as a policy-supporting document for nature conservation policy (Bogaert, 2004). In the policy note, the Groene Hoofdstructuur is described as "a coherent and organised complex of areas in which a more intensive nature conservation and development policies are appropriate" (de Blust et al., 1992, p.3). Municipalities in the Campine region were given a new responsibility of nature conservation and development policy (e.g. the land development project named Grote Nete investigated



Map 15 : Municipality of Herentals surrounded by hedged farm parcels and heathland plaggen areas. (Kabinetskaart Ferraris, 1777)



Map 16: Planning destination of the Regional Map of the Nete basin, for map's legend, see appendix A. Mapped by Sebastien Van Eupen, data source: geopunt.be

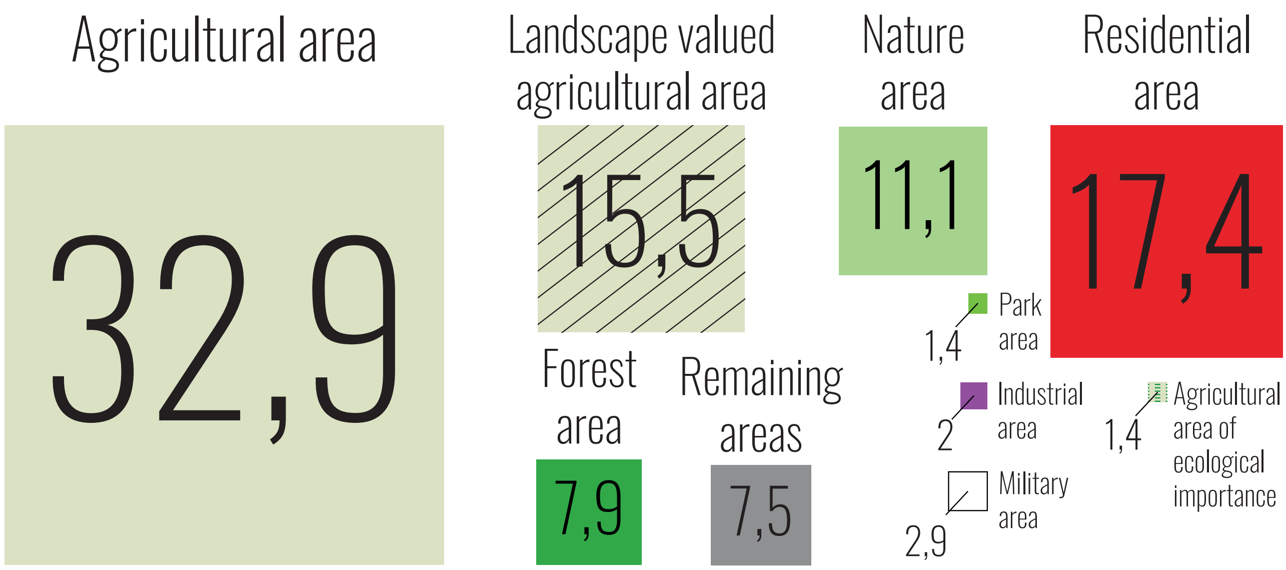


Figure 6: Share (in %) of the planning destinations of the Regional Zoning Plan in the Nete basin, figure developed by Sebastien Van Eupen, data sourced from GIS-analysis on map 16

harmonic spatial planning concepts for agriculture, nature, traffic, water and recreation (Verhagen & de Blust, 1995). However, Dewaelheyns et al. (2012) state that the regional and nature development policies did not translate to a significant extent into the handling of (environmental) permits. For example, in 1992, a permit was granted to develop a recreational area in a nature conservation area, assigned by the Groene Hoofdstructuur-map (Bogaert, 2004; Dewaelheyns et al., 2012; de Blust et al., 1992).

From 1993, nature organisations' acquisition of nature reserves was met with subsidies, and different sectors and policy levels gained financial resources via European projects to develop sustainable projects. Dewaelheyns et al. (2012) state that "the restoration of natural values, the reduction of environmental damage and the realisation of rural development became common objectives." (p. 113). However, these common objectives did not always translate into the permit granting process (Bogaert, 2004; Dewaelheyns et al., 2012).

Since 1997, the Flemish Structure Plan has aimed to preserve an open character in rural areas for agriculture, nature and forests (Departement Omgeving, n.d.). In dialogue with nature and agricultural organisations, the Flemish Government agreed in 1997 to develop 750 000 ha of agricultural area, 150 000 ha of nature area and 53 000 ha of forest area, resulting in an increase of 38 000 ha of nature area, 10 000 ha of forest area and a decrease of 56 000 ha of agricultural area. In 2001, the Flemish government decided to delineate agricultural, nature and forest areas in two phases. In 2003, 86 500 ha of existing nature area would be designated as part of the Flemish Ecological Network (VEN), and since 2004, the process of agricultural, nature and forest areas delineation is being elaborated. In 2007, in cooperation with municipalities, provinces and civil society organisations, the Flemish government developed a spatial vision for agriculture, nature and forests in thirteen rural regions, including the area of the two Nete rivers: Kleine Nete and Grote Nete. This vision document forms a legal basis for the Regional Spatial Implementation Plans (GRUPs) to implement agricultural, nature and forest delineations on parcel level detail (Ruimtelijke Visie Voor Landbouw, Natuur En Bos - Regio Neteland, 2006). The Regional Spatial Implementation Plans aimed to develop zoning changes from agricultural areas to nature areas or vice versa within the consensus area. Policy objectives, as described in the spatial vision document Neteland, focus on (1) safeguarding coherent agricultural areas for professional agricultural practices; (2) preservation of cultural landscapes and structuring landscape elements; (3) enhancing the touristic recreative potential by connecting open space areas. Especially the policy objectives of (4) preservation and enhancing existing natural structures and integrating them into a network; (5) preservation and enhancement of valley structures and water systems for natural water storage; and (6) preservation and enhancement of existing forest and parc structures relate to drought mitigation strategies. Through these objectives, the spatial vision document Neteland creates spatial conditions that support "integrated water policy, strengthen relationships between watercourses and the surrounding valleys and guarantee the preservation of the existing ecotopes" (Ruimtelijke Visie Voor Landbouw, Natuur En Bos - Regio Neteland, 2006, p. 9). The vision refers to the importance of providing space to preserve and restore the water-retaining function of river valleys, restore natural river flows, decrease river water discharge, and enhance watercourses' buffering capacity. Therefore, "land use in river valleys should respect these natural dynamics of the water system" (Ruimtelijke Visie Voor Landbouw, Natuur En Bos- Regio Neteland, 2006, p. 9). Section 4.2 further elaborates a potential spatial policy basis for potential drought planning strategies in the Nete basin, focused on different case studies.

4.2 Spatial planning strategies to increase drought resilience in the Nete basin

Climate change can be a catalyst for a sustainable approach to the scarce open spaces in Flanders (Gullinck et al., 2012). Foré et al. (2012) state that "climate change makes us more aware of the necessity to link spatial development to the physical system and the existing spatial structures. [...] when we revaluate the role of landscape as an interaction between natural and human factors, we must again search for a good relationship between natural and human activities. The question is then: what can the future role of landscape be, and can we reintroduce the function (energy production, fuel, water buffering, food production) that were historically taken away from it? " (p. 128).

Many authors, such as Basche & DeLonge, 2019; Bean et al., 2007; Cai et al., 2015; Lehmann, 2010; Meerow et al., 2016; Pena et al., 2016; Querner & van Lanen, 2001; Solh & van Ginkel, 2014; Starke et al., 2010 underline the importance of soil rainwater infiltration to mitigate drought effects. However, several aspects need to be considered when developing strategies for rainwater infiltration (de Sutter et al., 2012). Infiltration is limited by soil texture[1] and soil hydrology (Davie, 2008). Furthermore, land use affects infiltration due to soil sealing and soil compaction (e.g. agricultural machinery or cattle hooves compact the soil, preventing water infiltration (VLM, n.d.; Oppong Tuffour et al., 2014).

Additionally, climate change threatens the water supply on two fronts. On the one hand, climate change will increase the pressure on water supplies from groundwater sources in Flanders during the drier summer season. On the other hand, a decrease in average summer precipitation and an increase in average evaporation will mainly be at the expense of the net precipitation surplus that can infiltrate deeper ground layers. Therefore, from a planning perspective, the declining amount of rainwater available should be enhanced to infiltrate the soil as much as possible. Therefore, this thesis aims to develop effective spatial planning strategies to increase water infiltration and retention in the Nete basin and increase the basin's drought resilience.

Additionally, Foré et al. (2012) note that implementing spatial drought strategies should consider the current main landscape structures as a basis for design concepts. Secondly, Foré et al. (2012) state that in designing climate-robust landscapes, the traditional protectionist, sectoral vision of nature as a low dynamic planning destination should be shifted towards an approach of nature as a "strong adaptive basis of the landscape" (p. 129). This flexible interpretation of implementation and functions provides a more robust basis for the current (climate) needs. "Of course, its interpretation cannot be left completely free. It is important in an ecosystem-based approach to start from cross-sectoral objectives, whereby the functioning of a qualitative physical system is the test. In order to meet the great pressure on space, spatial synergies are also sought for various objectives" (Foré et al., 2012, p. 129).

The following sections investigate potential drought strategies in the Nete basin. The insights from Foré et al. (2012), de Sutter et al. (2012), de Waegemaeker et al. (2017), Dewaelheyns & de Waegemaeker (2012) and Staes et al. (2021) form a basis for the development of different specific cases in the region of the Kleine Nete river. The case study's proposed drought strategies mainly consider nature-based solutions.

1 Soil texture is a summation of proportions of sand, silt and clay content (Upadhyay & Raghubanshi, 2020).

4.2.1 The potential for reducing soil sealing in the Nete basin

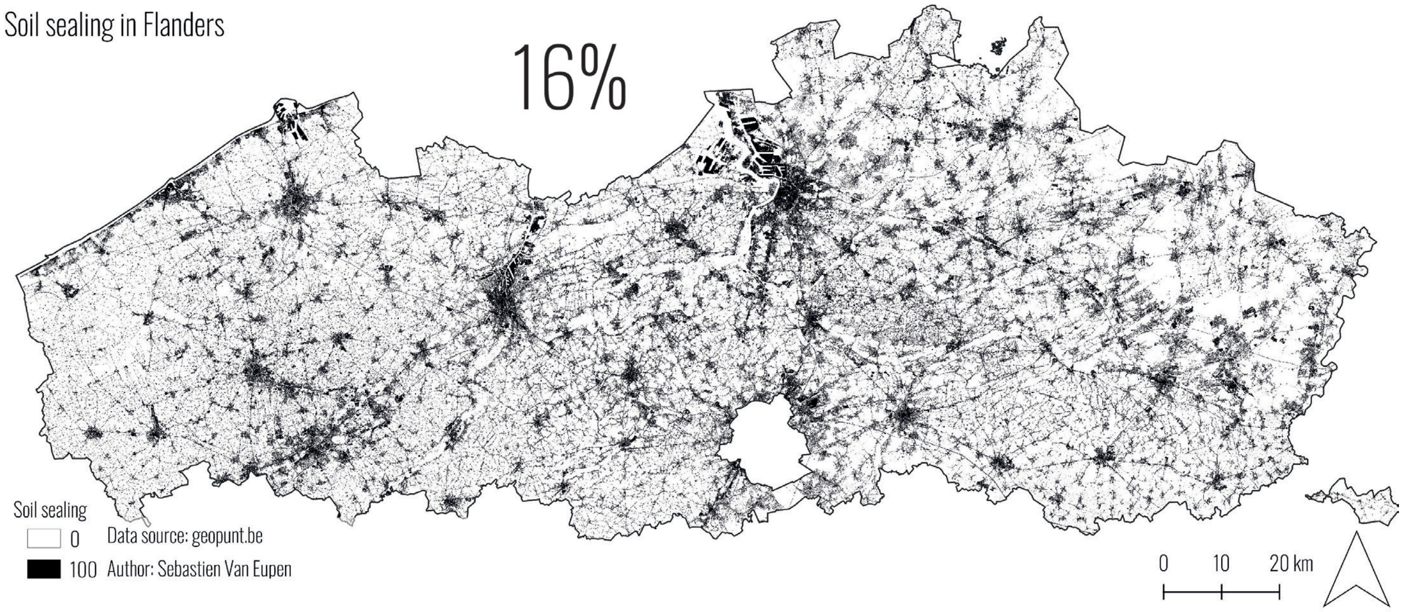
In East Asia, North America and Europe, cultivated land has been extensively converted into built-up areas that can increase the severity of problems associated with drought (Azadi et al., 2018). This reduces the influx of groundwater, causes lower water reserves in aquifers, and increases the extent and frequency of intensive floods. Morgenroth et al. (2013) note that urban soil moisture content could be significantly increased with porous pavement, but this would also alter the soil chemistry, resulting in higher concentrations of Na. Urban rainwater infiltration could potentially compromise groundwater quality.

Due to soil sealing, the spatial arrangement of built-up areas in Flanders enhances the susceptibility to drought (Waterbeleidsnota 2020 - 2025, Deel Waterbeheerkweties, 2020). The term soil sealing refers to the permanent covering of an area of land and its soil with impermeable artificial materials, such as asphalt and concrete (European Commission, 2012).

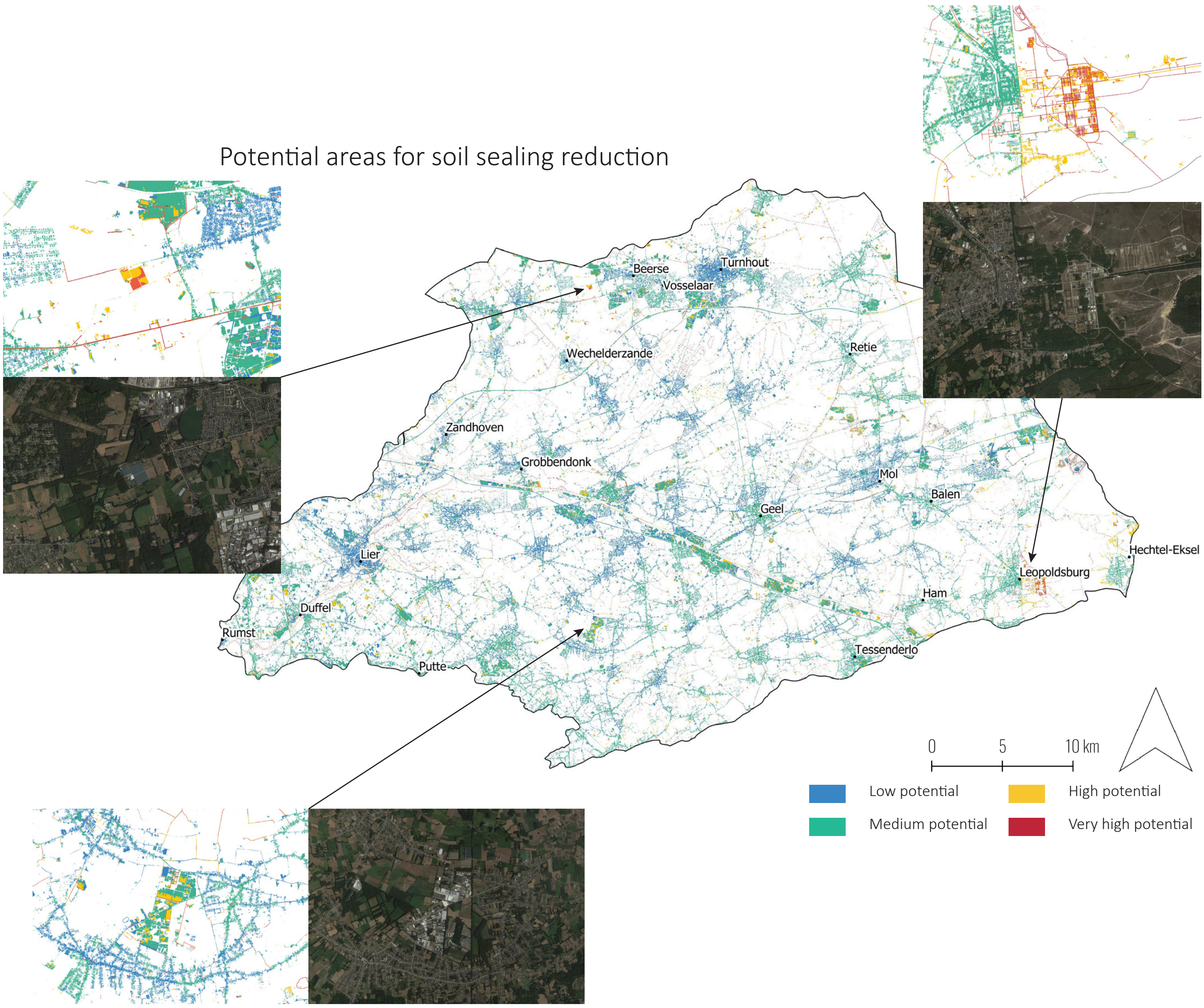
16% ± 1,2% over Flanders' surface is sealed (map 17). Reducing sealed soil to enhance rainwater infiltration is one of the central themes in the Whitebook Spatial Policy Plan of Flanders (Departement Omgeving, 2019). Furthermore, the Strategic Vision of the Spatial Policy Plan of Flanders (2018) refers to exchanging impervious to porous pavements to enhance rainwater infiltration. Porous pavements increase evaporation (Starke et al., 2010) and infiltration (Bean et al., 2007) rates and potentially mitigate the city's drought. Additionally, Lehmann (2010) refers to the function of the soil to buffer climate extremes, mainly through cooling by evaporation from the surface and evapotranspiration from soil-grown vegetation. Therefore, sufficient soil moisture content levels are essential for developing this temperature buffer potential in urban areas. Soil moisture content could increase by replacing impervious pavement with porous pavement (Morgenroth et al., 2013). Querner & van Lanen (2001) also state that urban expansion combined with stormwater infiltration measures mitigates drought.

Section 1.4 already hints that reducing soil sealing in urban areas to mitigate drought would potentially not have a significant effect. For example, since 54% of Flanders' area consists of infiltration sensitive soil, decreasing the 16% of sealed soil in Flanders by 1 – 2% would not significantly mitigate drought. Additionally, reducing soil sealing in an urban area situated downstream of the river basin (e.g. the city of Antwerp) would not significantly affect drought mitigation. In this case, the infiltrated water is already close to the estuary and the sea. Therefore, it does not significantly contribute to groundwater reservoirs. Consequently, focusing exclusively on sealed surfaces alone would not be sufficient for an effective drought policy. Nonetheless, there is potential to reduce soil sailing in the Nete basin (map 18).

Map 18 highlights the potential to reduce soil sealing in the Nete basin. Towns and adjacent ribbon development present lower to medium potential to reduce soil sealing. However, the accompanying maps on map 18 suggest that industrial areas and areas such as the military school of Leopoldsburg in the east, which are characterised by relatively large soil sealed surfaces, present the highest potential to reduce soil sealing.



Map 17: soil sealing in Flanders, mapped by Sebastien Van Eupen, data source: Geopunt.be



Map 18: the potential for soil sealing reduction in the Nete basin, mapped by Sebastien Van Eupen, data source: geopunt.be

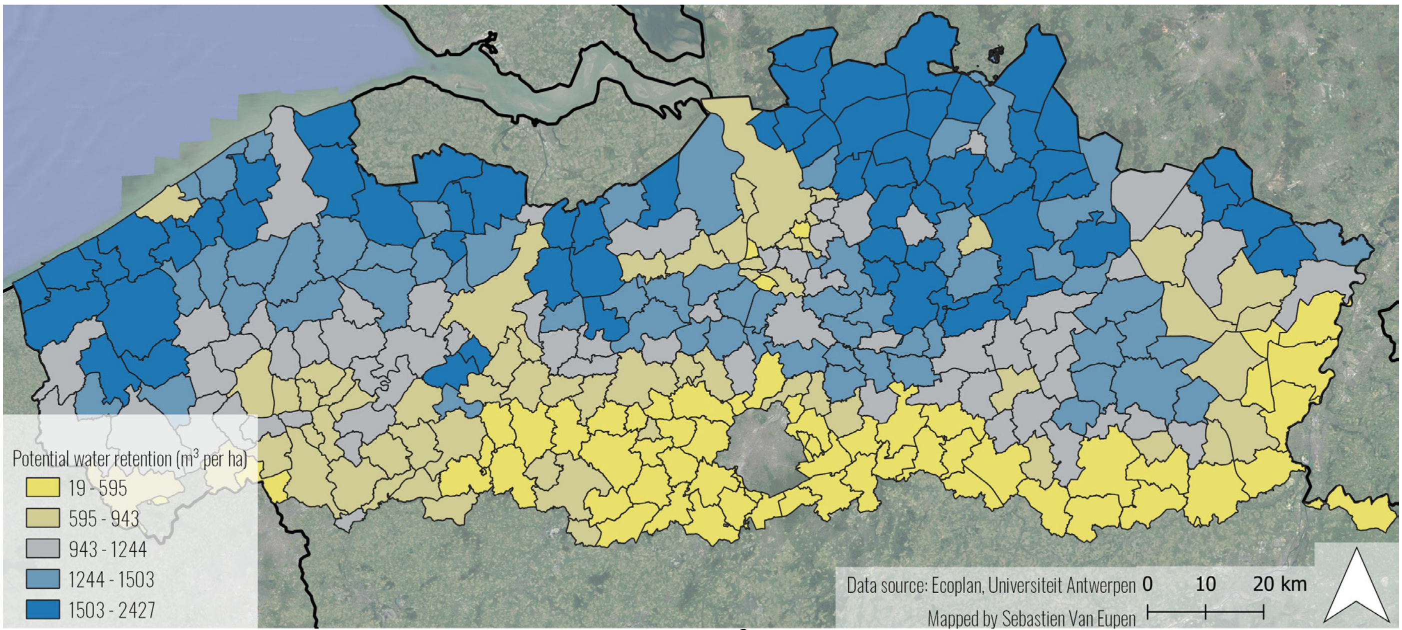
4.2.2 Enhancing water infiltration and retention from the Nete basin perspective

The river valley of Kleine Nete is vulnerable to floods and droughts (Decock, 2021). Thus, water retention and infiltration strategies could provide mitigation solutions. Map 19 presents the potential for water retention per municipality. The sandy soil in the Campine region shows a high potential for water retention. Until agricultural drainage activities started, the valley of the Kleine Nete river was dominated by peat wetlands (Verhoestraete & Staes, 2019). The surrounding sandy elevated landscape acted as infiltration areas, which provided the wetland's water. Much of these elevated areas were planted with pine trees for economic purposes, reducing their infiltrating capacity. Additionally, dikes were implemented along Kleine Nete to accelerate downward river discharge, which increased flood risks in lower-lying areas of the Nete basin. "With today's knowledge, it is safe to say that this was a huge historical mistake" (Verhoestraete & Staes, 2019, p. 3).

de Waegemaeker et al. (2017), de Sutter et al. (2012) and Foré et al. (2012) state that for drought-mitigating strategies, there has to be a larger focus on infiltrating rainwater in the upstream region of the river basin, at elevated areas in the landscape and on a certain distance from the draining watercourse. The latter ensures a relatively deeper groundwater table and better conditions for rainwater infiltration. A groundwater table close to the surface enhances conditions of oversaturation of the soil. This mechanism is illustrated in figure 7. Implementing rainwater infiltration strategies at these locations could potentially conflict with existing agricultural practices in the area.
Map 23 (section 4.2.2.1) presents the elevated regions' land use in the landscape of the Nete basin. These elevated areas with sandy soils and a mild slope gradient facilitate high infiltration capacities (Birot et al., 2011).

Next to elevated areas as places for water infiltration, different low-lying and historically wetter areas could play a role in buffering and retaining water. Wetland restoration has drought and flood mitigation potential. Research in the German Middle Mountains indicates that wetland restoration can decrease flooding risk in downstream areas (Kersbergen et al. 2020). Additionally, according to their WFLOW-model predictions, "wetland restoration increases low flow river discharge by approximately 10% - 30% in the summer and fall" (Kersbergen et al., 2020, p. 31). In the case of the Campine region, developing wetland can improve the sponge (water retaining) function of the river basin and therefore increase summer water availability. The Nete basin contains several historically wetland areas, which were drained for agricultural purposes. In the last 50 – 60 years, Flanders lost about 75% of its wetland habitats, with only 68 000 ha remaining, often in a more or less degraded state (Decleer et al., 2016). Dutch toponyms such as "broek, broeck, brouck" in place names refer to historically wet, marshy areas (e.g. "Geels Gebroekt", is the name of the former wetland area near the municipality of Geel, today, the nature reserve in this area is named De Zegge (Ceulemans, n.d.)). Areas with these toponyms could potentially harbour or develop a water-retaining function. This is addressed in section 4.2.2.2 with the nature reserve De Zegge as a case study.

A similar Chinese urban planning strategy named the Sponge City concept has been implemented since 2013 in Sout-East Asia (Nguyen et al., 2019). These urban planning strategies mainly focus on flood damage reduction by enhancing urban water infiltration, retention and developing stormwater storage capacities for water supply purposes. Although the Chinese Sponge City concept primarily focuses on urban areas and less on the river system itself. Nonetheless, Nguyen et al. (2019) mention the need to develop upstream water retaining typologies to reduce flood risks.



Map 19: Potential water retention per municipality (in m³ per ha), data source: Ecoplan, Universiteit Antwerpen, mapped by Sebastien Van Eupen

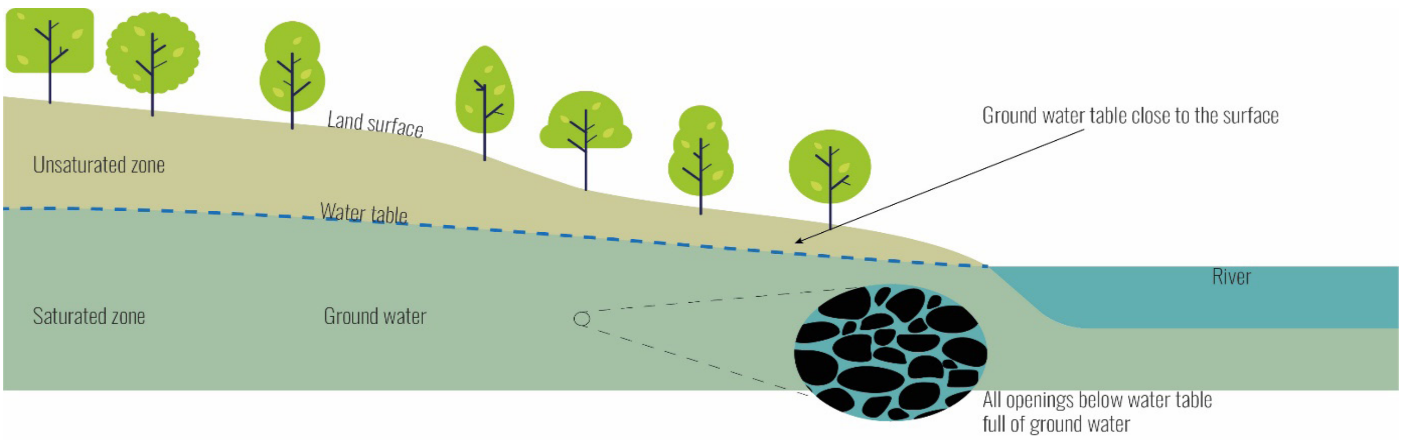


Figure 7: illustrating the relationship between the water table and the land surface, illustration developed by Sebastien Van Eupen, Adobe Illustrator tree templates sourced from vecteezy.com/diana.

Due to an increased river system sponge function, restored wetland could contribute to a high potential for nature development and increased water availability for the industry along the Albert Canal (Foré et al., 2012). A significant stakeholder in landscape changes resulting from implementing drought strategies is agriculture. Therefore, drought strategy concepts should consider nature development and economic (agricultural) efficiency. The following sections focus on the potential of different spatial planning strategies to increase drought resilience by increasing rainwater infiltration and retention rates along the river Kleine Nete. Gulinck et al., (2012) state that

> "In the first place, efforts must be made to ensure the quality of the delimited nature structures such as the VEN (Flemish Ecological Network) and the NATURA-2000 network. Furthermore, achieving the conservation objectives of the Habitats Directive and the related nature management and development will also provide opportunities for climate adaptation and mitigation" (p. 93).

Map 20 presents the location of the Natura-2000 areas in the Nete basin. The light green areas, referring to "search area" on map 20, indicate areas considered valuable in the context of conservation objectives and Habitat Directives, but they are not (yet) organised as such. Natura-2000 areas could potentially be appropriate locations to implement spatial drought resilience strategies and provide a legal basis.

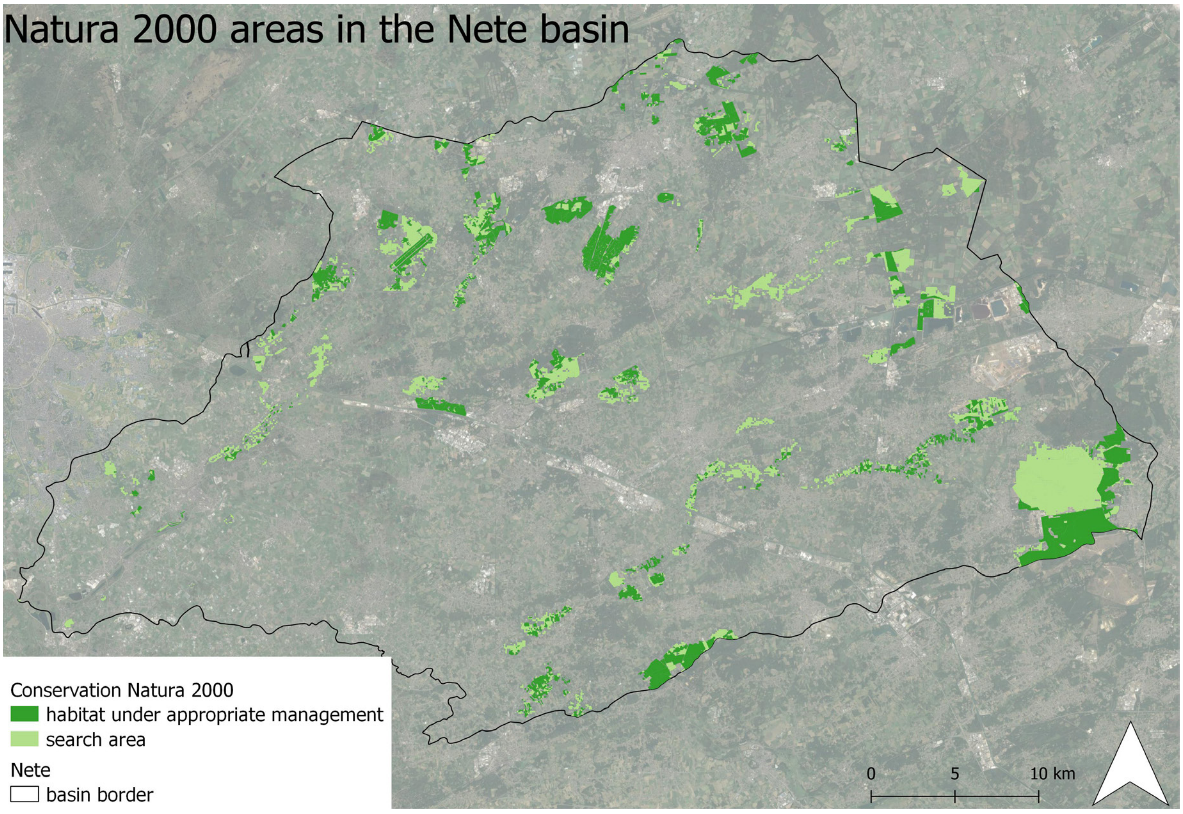
Foré et al. (2012) conducted a research-by-design methodology to investigate and develop climate robust vision plans for the Campine region. The designs focused on an upstream part of the Grote Nete river, highlighted in red on map 21. Foré et al. (2012) findings shall be used as a basis to explore potential drought mitigation typologies for a region surrounding the Kleine Nete, delineated in black on map 21.

Map 22 presents the case study area (as delineated by a black polygon on map 21) of the following sections. The area is cross-sectioned by the river Aa and Kleine Nete and the Canal Herentals – Bochelt. The land cover differentiates between housing, gardens, industry and recreation (grey, black saturation filter on map 22), agriculture and forests (highlighted green saturation filter on map 22).

The identity of a landscape can play an essential role in developing a vision for landscape changing policy (Dewaelheyns & Foré, 2012). With the development of participatory spatial policy concerning climate change adaption and drought mitigation, the integration of recognisable landscape components offers essential advantages in terms of recognition, familiarity and social involvement with a particular place. Allaert (2006) and Selman (2006, as cited in Dewaelheyns & Foré, 2012) state that radical landscape changes are best embedded in a thorough participatory process, where local inhabitants can influence and even co-create the vision of the landscape changes. Many authors, such as Albrechts (2017) and Coppens (n.d.), state that Flanders' degree and quality of participation processes have increased in the last decades.

The following sections present concrete design strategies for different case studies in the Nete basin. These typologies are developed from academic literature research, policy document research, and GIS analysis, not participatory processes.

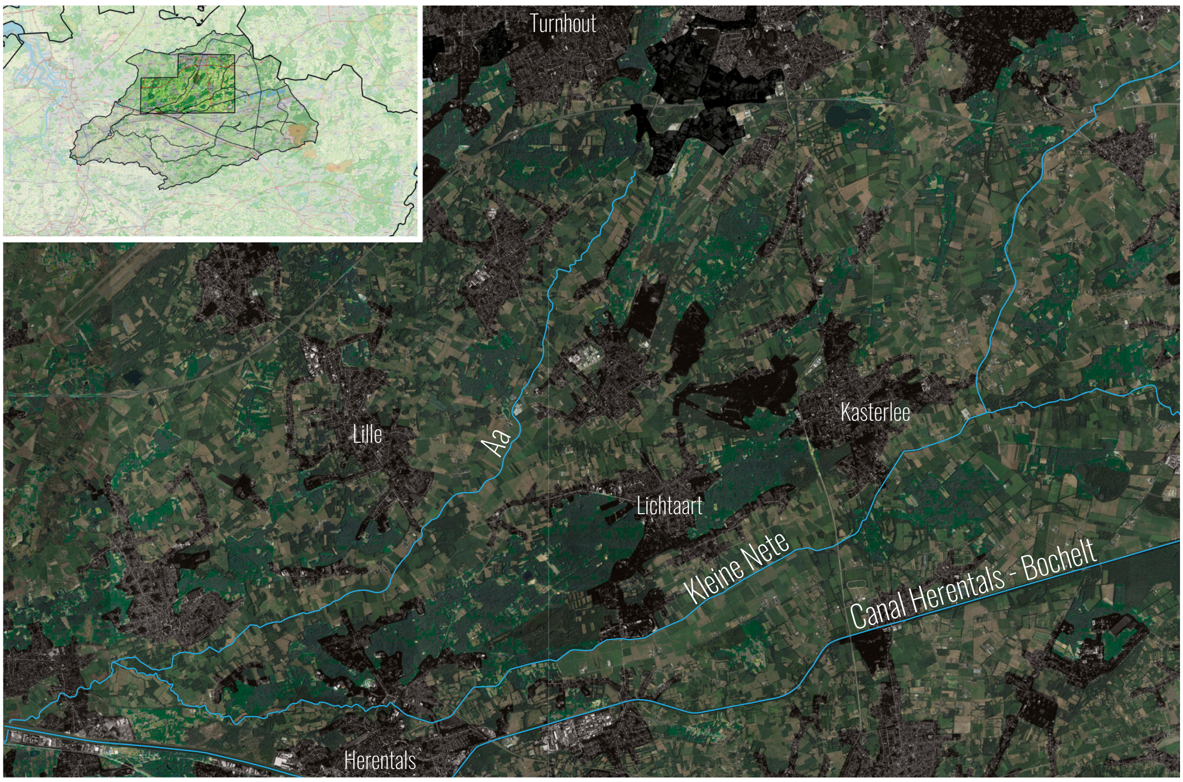
Map 20: Natura 2000 areas in the Nete basin, mapped by Sebastien Van Eupen, data source: Geopunt.be



Map 21: vision map by Foré et al. (2012)

Map 22:

Case study area near the Kleine Nete and Aa river.



4.2.2.1 Drought strategies on the elevated areas of the Nete basin

The sandy soils of the Nete basin, in combination with a relative deep groundwater table on elevated areas in the landscape, have a high rainwater infiltration potential (Gullinck et al., 2012). To improve rainwater infiltration, spatial designers should consider certain vegetation types. Van Hoydonck et al., (2001) state that heathland, grassland and shrubbery tend to have a higher rainwater infiltration potential (75%). Deeply rooted vegetation, such as forests, can use a relatively larger amount of ground- and rainwater due to higher rainwater interception and transpiration rates. Rainwater interception and transpiration rates can differ significantly between tree species. For example, oak forests have a 30% infiltration potential compared to coniferous forests with a 15% infiltration potential. Therefore, the infiltration potential of forests is at the same level as agricultural parcels (van Hoydonck et al., 2001).

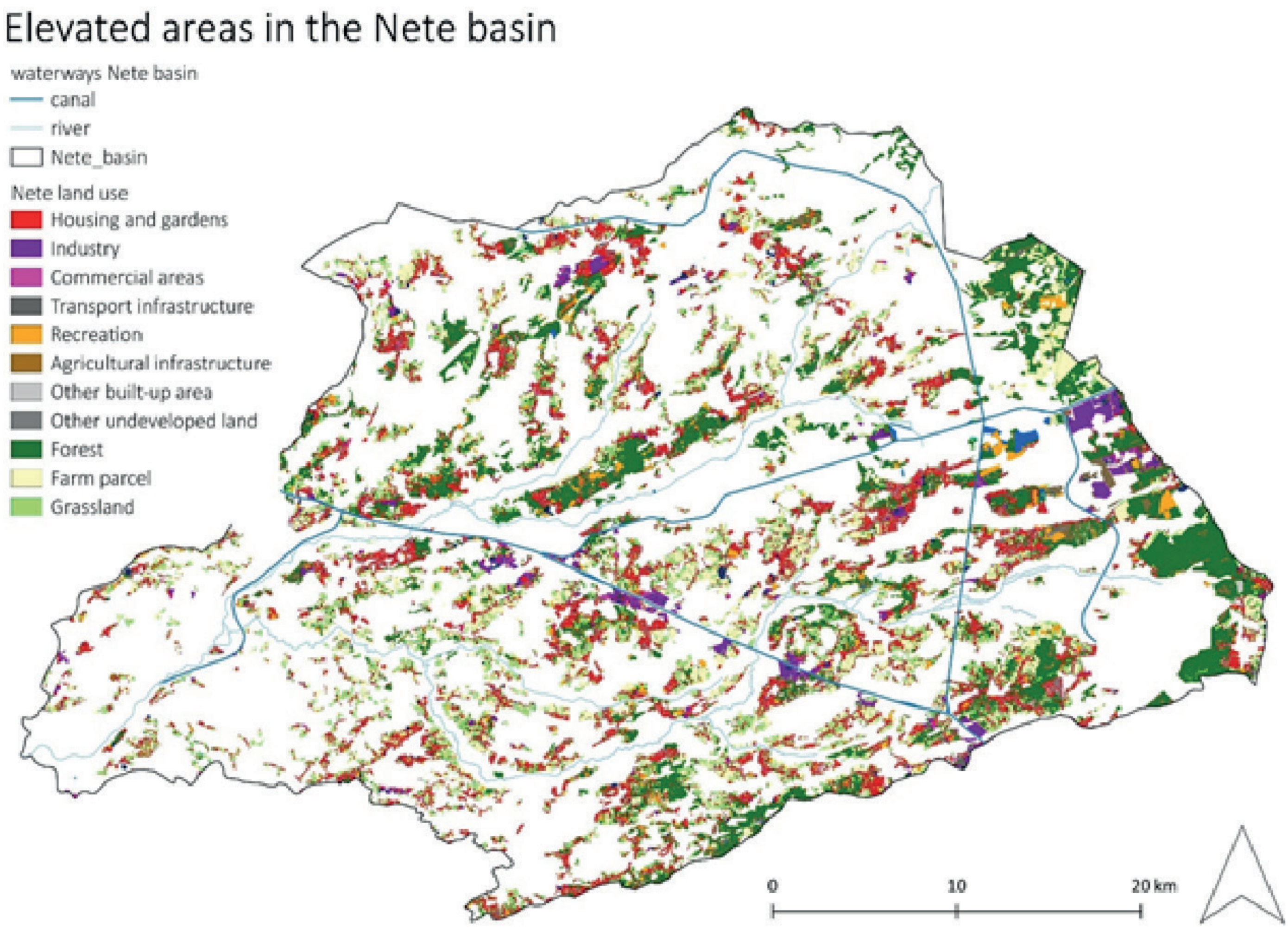
Map 23 presents different land uses on elevated areas in the Nete basin. The delineation of the elevated areas on map 23 was derived from the Physical System Map of the Vlaamse Landmaatschappij (Agentschap Informatie Vlaanderen, 2010). The data from map 23 was extracted with QGIS and analysed in MS-Excel to develop graph 1. Graph 1 presents the total area per land use for these elevated areas, which mainly consist of farm parcels (21,06%), housing and gardens (17,04%), grassland (13,43%), forest (9,63%) and recreational areas (9,16%).

The following sections focus on developing drought strategies on elevated farmland and grassland. Housing and gardens will be briefly considered in section 4.2.2.3, but it is not the primary focus of this thesis. As a planning destination, residential areas cover 17,4% of the Nete basin in the Region Plan (figure 6, section 4.1.2). The majority of the Nete basin is covered by an agricultural planning destination (48%). Additionally, section 4.2.2.1.2 focuses on a particular type of elevated area: the sandy dunes of the Campine region.

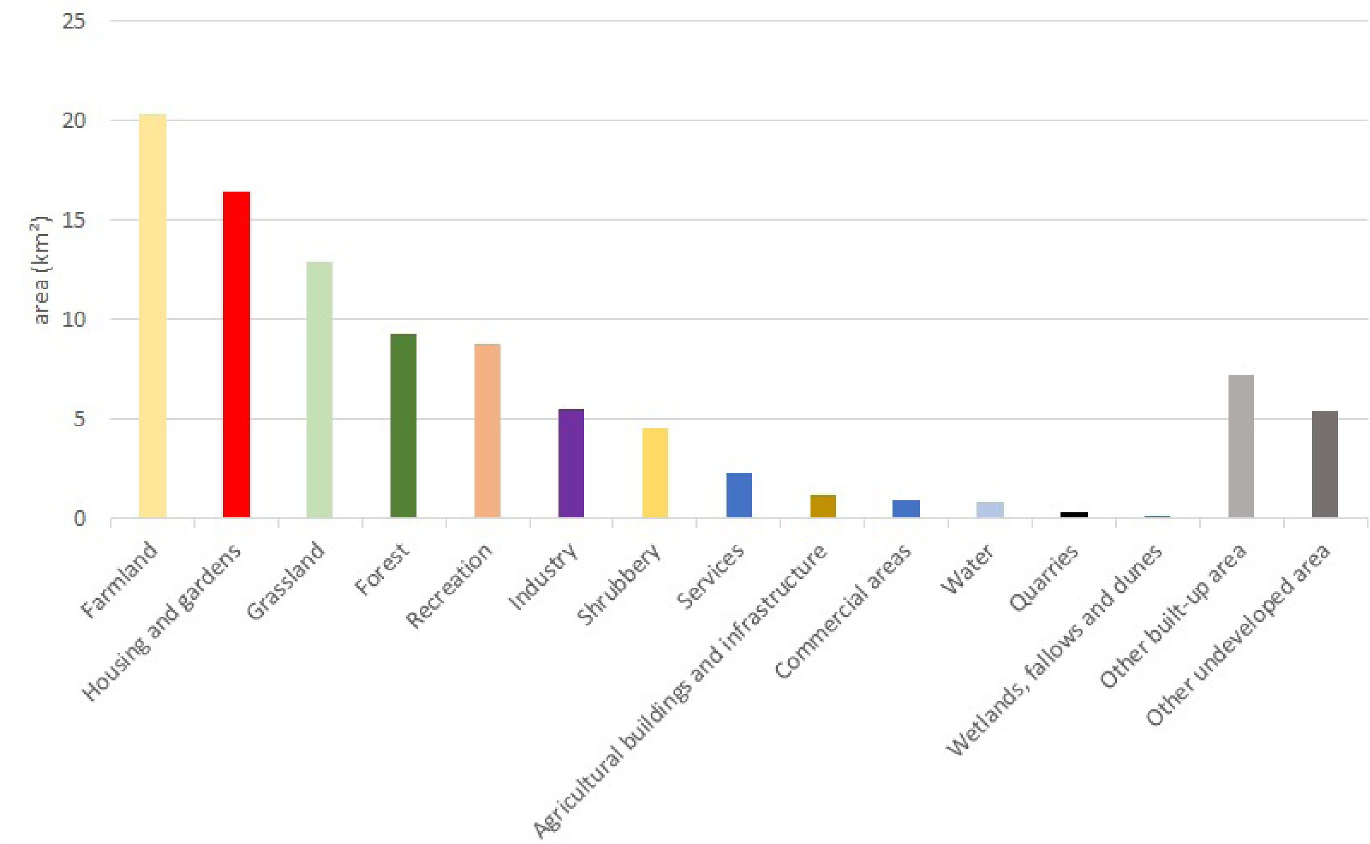
4.2.2.1.1 Drought mitigating agriculture on elevated areas in the Nete basin

As mentioned, heathland (Van Hoydonck et al., 2001) and elevated areas in the sandy Campine region (de Sutter et al., 2012; de Waegemaeker et al., 2017; Foré et al., 2012) present a high rainwater infiltration potential. Therefore, transforming the land use of these elevated areas into heathland would significantly impact rainwater to groundwater flow. The resulting drought planning strategies of heathland development on elevated areas would mostly impact agriculture based on the surface area on these elevated areas (graph 1). Agriculture could profit from drought planning strategies as this sector is expected to experience significant climate change impacts (Azadi et al., 2018; Wambura & Dietrich, 2020).

Regional dynamic crop models (REGCROP), developed to assess the impact of climate change on arable crop production in Belgium, present that future climate change impact scenarios result in average yield losses of 12 – 27% for sugar beet and 23 – 44% for potatoes due to heat stress (Gobin, 2010). Boardman et al. (1994) state that sugar beet, potatoes, and maise croplands in Belgium are prone to runoff during the summer months, resulting in flooding. “Runoff is a loose term that covers the movement of water to a channelised stream after it has reached the ground as precipitation” Davie, 2008, p. 75. Limiting runoff enhances rainfall infiltration, which contributes to drought mitigation and agricultural productivity. The hilly and agricultural areas of central Belgium present much runoff, resulting in relatively high flood risks (Boardman et al., 1994). Therefore, addressing agricultural runoff with planning strategies can provide a win-win situation for drought mitigation and flood risk reduction.



Map 23 : land use on elevated areas in the Nete basin. Data source land use: geopunt.be, mapped by Sebastien Van Eupen

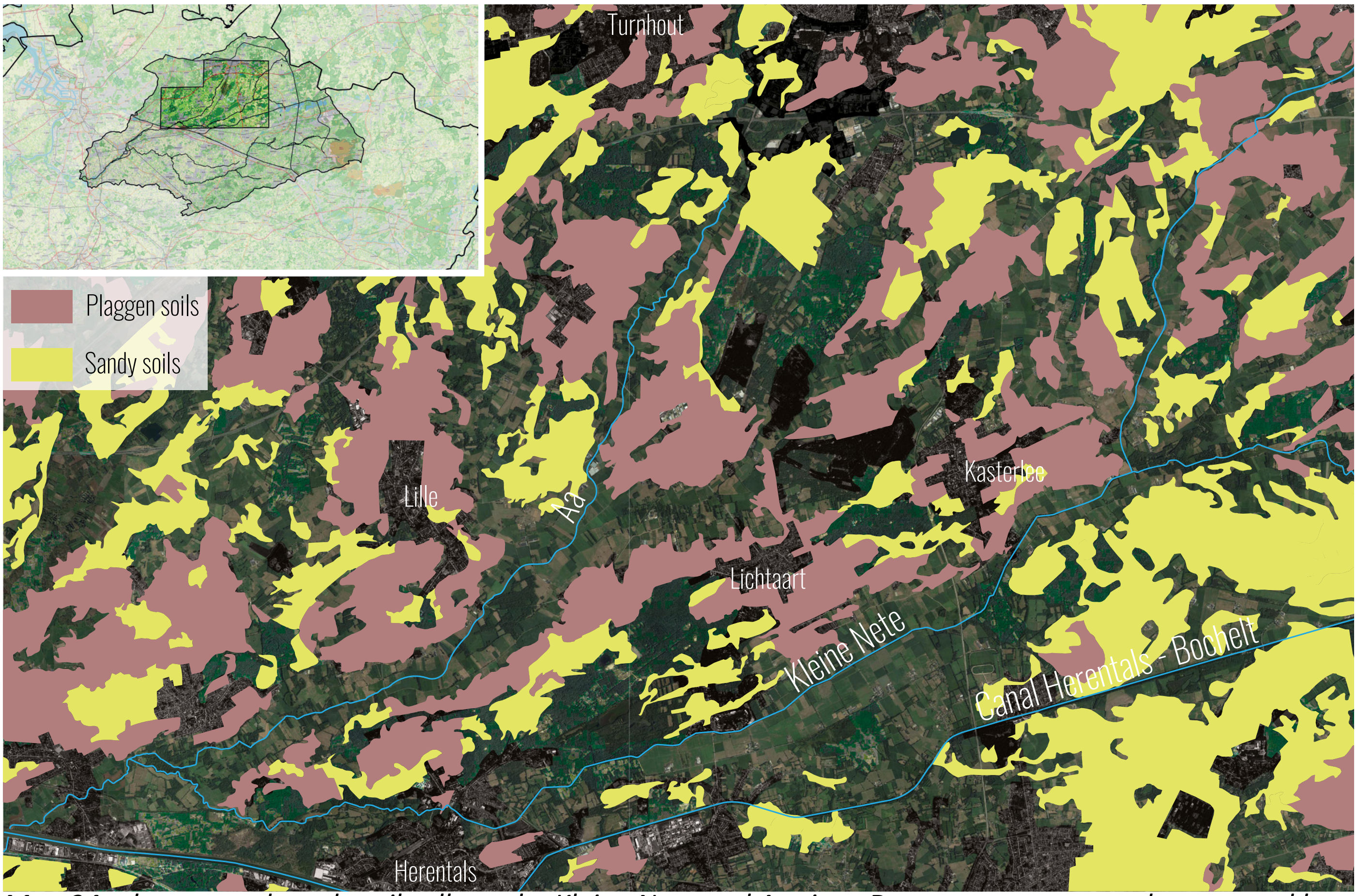


Graph 1: area (in km²) per land use for elevated areas in the Nete basin.

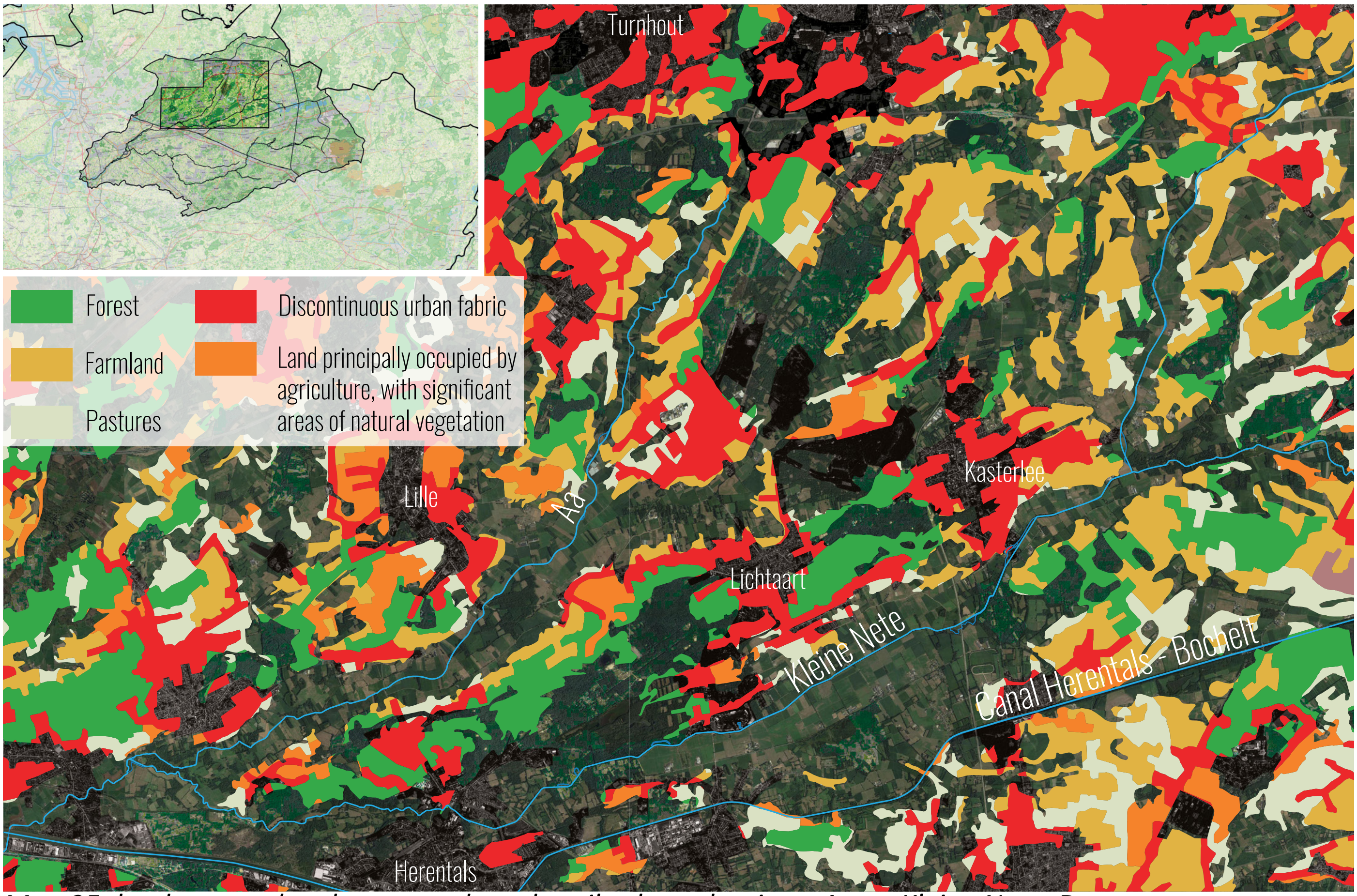
Additionally, developing and implementing more drought resilient agricultural practices provides potential. The increasing drought risks suggest that a geographical agricultural shift could be appropriate (Solh & van Ginkel, 2014), where current Flemish agrarian systems could be substituted by systems currently in more arid climates. Implementing dryland crop management principles could additionally be opportune: retaining soil moisture content by reducing evaporation; using drought and heat-tolerant crops and varieties that fit the shifting rainfall pattern and conservation agriculture. Implementing hedges bordering agricultural parcels and agricultural practices with permanent vegetation (e.g. trees) increases soil water content (de Sutter et al., 2012). The root systems of this permanent vegetation cause the soil to be more permeable to rainwater.

More effective irrigation systems address inefficient water usage (Solh & van Ginkel, 2014). For example, converting gravity or surface irrigation schemes to pressured irrigation systems such as drip or sprinkler systems provides a technical solution to improve water use efficiency and lower groundwater dependency. Furthermore, expanding irrigation capacity with harvested water reserves, both from micro-and macro-catchment sources, could also contribute to drought mitigating agriculture. However, the concept of this case study focuses on increasing infiltration potential to increase the soil moisture and groundwater content. From this perspective, groundwater layers are approached as natural water reservoirs: the main water reserve throughout drier periods. Therefore, exploring spatial planning strategies that could increase the influx of rainwater towards groundwater layers in the Nete basin is the main objective of this thesis. “Nature is often the main target for adaptation measures, but in fragmented Flanders, with an appropriate design fields and meadows can also mitigate urban heat island effects and buffer floods” (de Waegemaeker, 2018, p. 1). de Waegemaker (2018) argues that a proper design and management of agricultural land contributes to a climate robust Flanders. Additionally, de Waegemaker (2018) states that spatial policies should conserve valuable agricultural land and finance its ecosystem services. To cope with nutrient-deficient soil, the traditional farming methods in the Campine region resulted in ***plaggen*** soils (Pape, 1970). These soils have been fertilized with a mixture of manure, sods and litter. This agricultural practice persisted for a long time and buried the original nutrient-deficient sandy soil under a humus-rich dark soil layer. Historically, these plaggen soils are covered by farmland with an open landscape. Foré et al. (2012) research-by-design concepts leans towards this historical background and suggest intensive agriculture on these plaggen soils’ farmland could be maintained. Rainwater runoff can be captured by trees and infiltration ditches bordering these relatively larger agricultural plots. Primarily oak trees could provide rainwater infiltration ecosystem services.

Map 24 presents the plaggen and sandy soils of the study area in the vicinity of the Kleine Nete river. In addition, map 25 shows the land use on these soils. Historically, a lot of the plaggen soils are situated near villages. Today, many plaggen soils are covered by housing and gardens due to urban sprawl dynamics in the 20th and 21th-century.



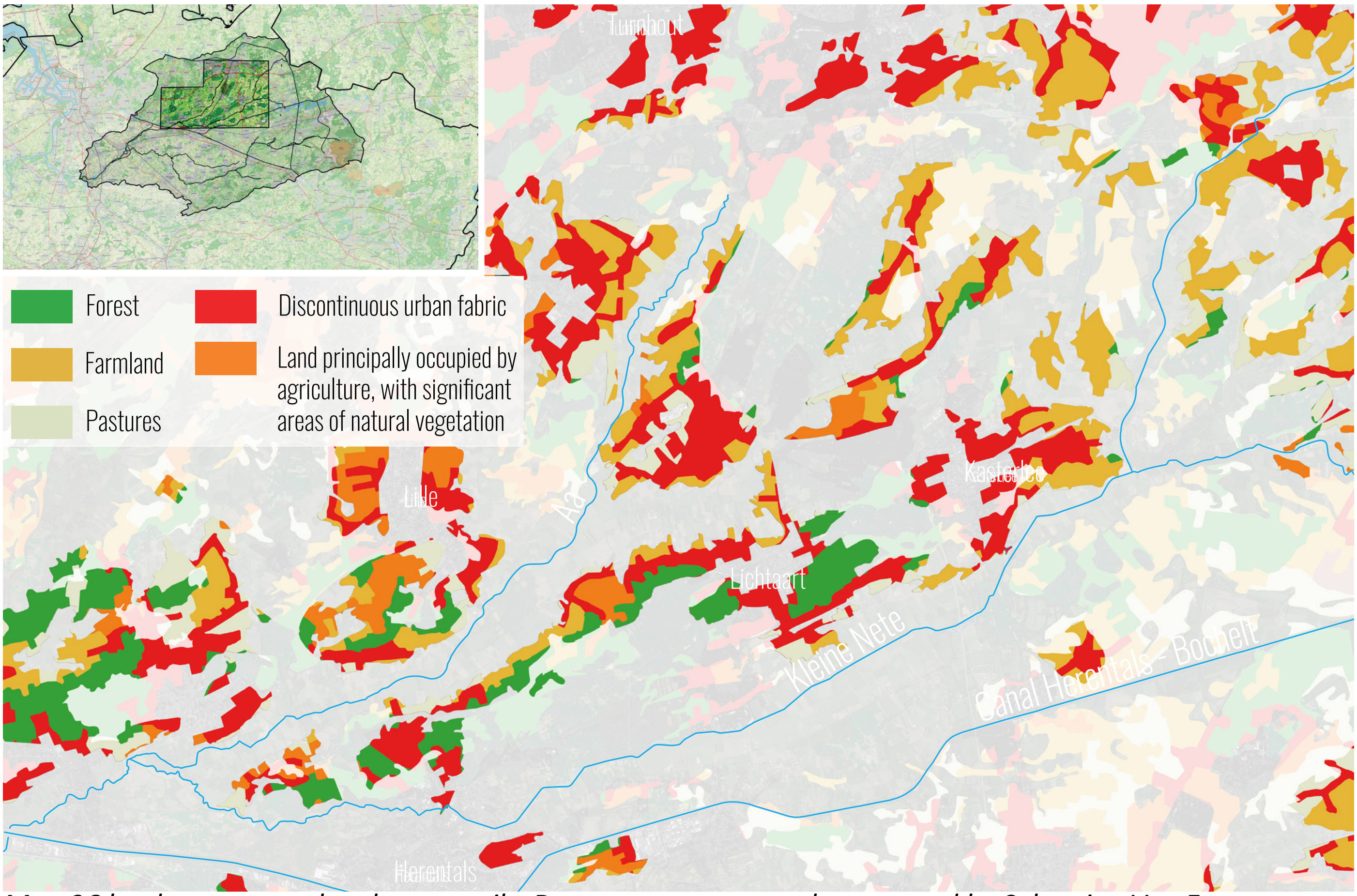
Map 24: plaggen and sandy soils allong the Kleine Nete and Aa river. Data source: geopunt.be, mapped by Sebastien Van Eupen



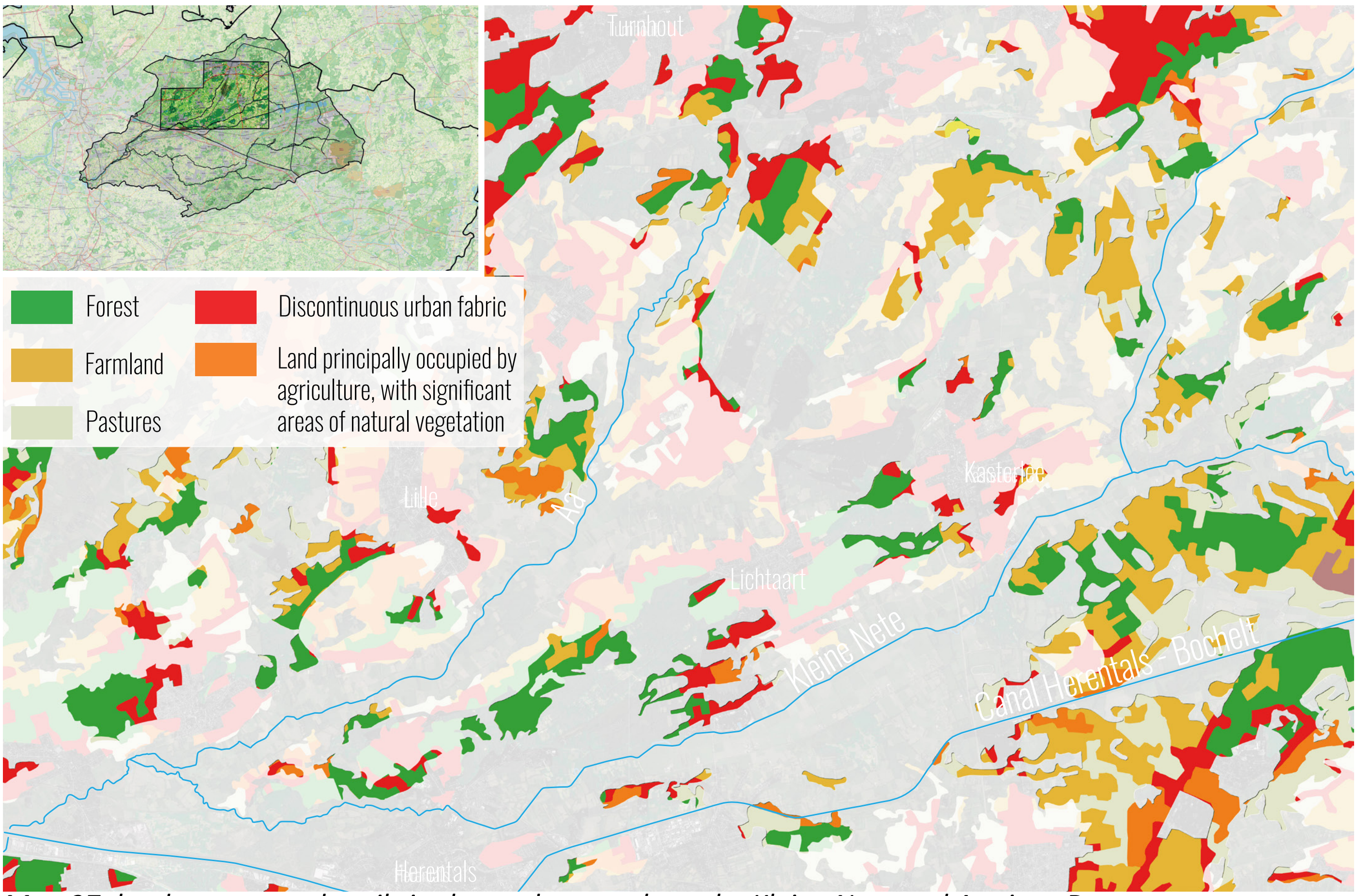
Map 25: land use on the plaggen and sandy soils along the rivers Aa en Kleine Nete. Data source: geopunt.be, mapped by Sebastien Van Eupen

Map 26 presents the land use and fragmented farmland (in dark yellow), which still sits on top of the plaggen soils. Following the suggestions by Foré et al. (2012), these farmlands could maintain their open character and intensive agricultural practices.

Map 27 presents the sandy soils' land use, with fragmented farmland (in yellow). The relative high infiltration potential and deep groundwater table of these sandy soils pose a high potential for rainwater infiltration (Birot et al., 2011; de Sutter et al., 2012; de Waegemaeker, 2018; Foré et al., 2012) and thus, drought mitigation strategies. By intensively bordering and subdividing these agricultural plots with tree rows and infiltration ditches, rainwater is enhanced to infiltrate into the soils.



Map 26 land use on top the plaggen soils. Data source: geopunt.be, mapped by Sebastien Van Eupen

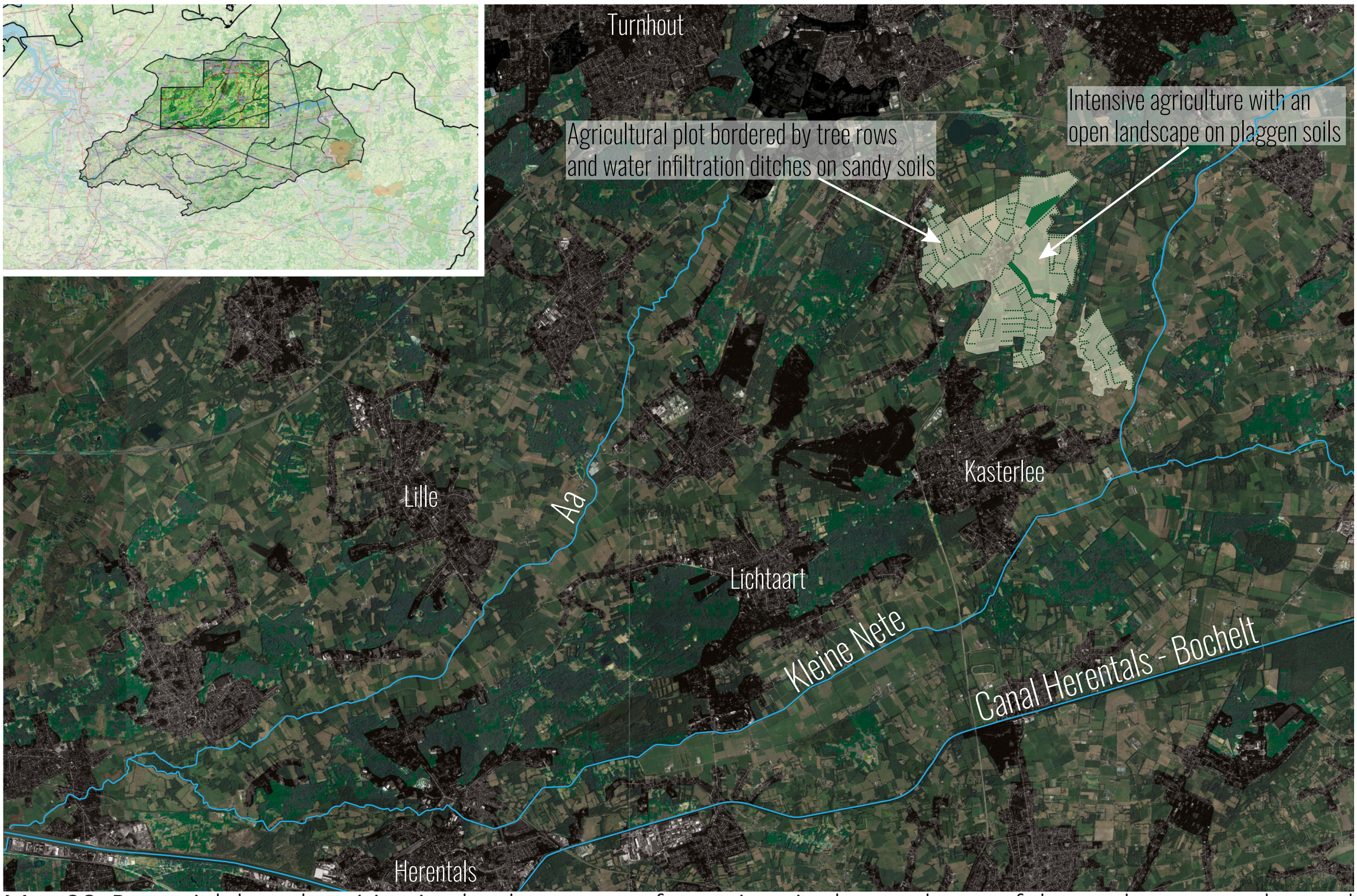


Map 27: land use on sandy soils in the study area along the Kleine Nete and Aa river. Data source: geopunt.be, mapped by Sebastien Van Eupen

Map 28 presents some agricultural plots in the northeastern part of the study area that covers sandy and plaggen soil. The farmland on the sandy soil could be restructured to increase its infiltration capacity from this analysis by bordering the farm parcels with tree rows. Map 28 presents the locations of the potential development of these tree rows. Currently, these parcel borders do not contain woody hedges or tree row structures. Additionally, map 28 presents agricultural parcels on top of plaggen soil, which could maintain their open landscape.

Water infiltration and retention can be increased on sloping sandy soils by implementing buffer zones of woody hedges, trees or trenches and ditches perpendicular to the slope (Raman et al., 2021). Figure 8 presents a vision of these woody hedges and trenches for the farmland north of the municipality of Kasterlee.

These woody hedges follow farmland parcel border and could provide a drought mitigating strategy that is less compromising on the current agricultural practices. Especially, if an open landscape character is maintained on the plaggen soils.



Map 28: Potential drought mitigating landscape transformations in the northeast of the study area on elevated agricultural plots. Data source: Geopunt, Google Earth data. Mapped by Sebastien Van Eupen

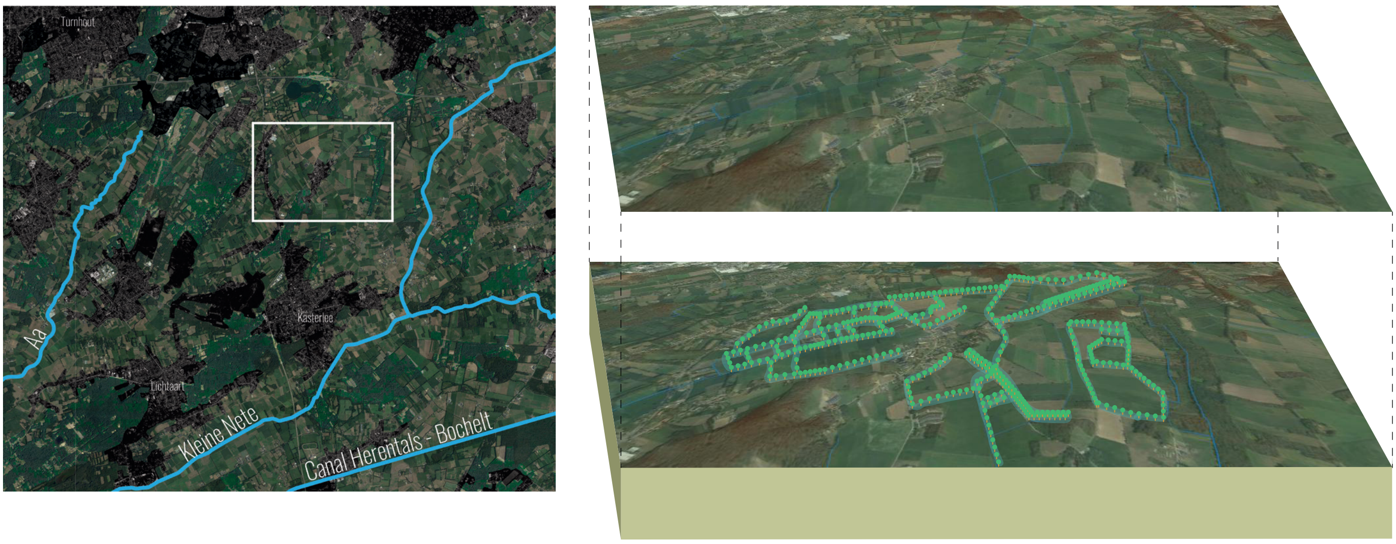


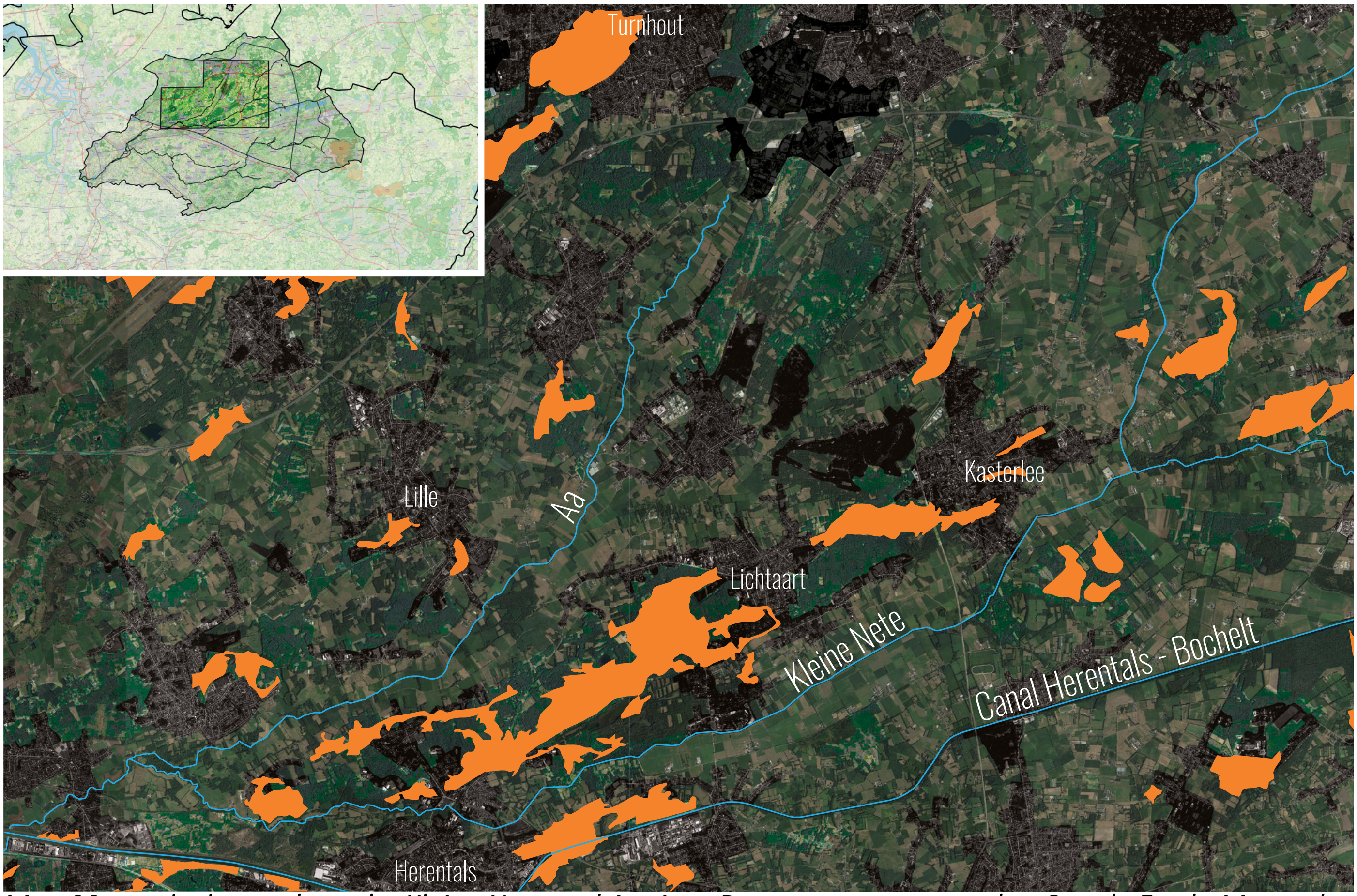
Figure 8 woody hedges bordering farm parcel to enhance water infiltration

4.2.2.1.2 Improving the water infiltration on the sandy dunes in the Nete basin

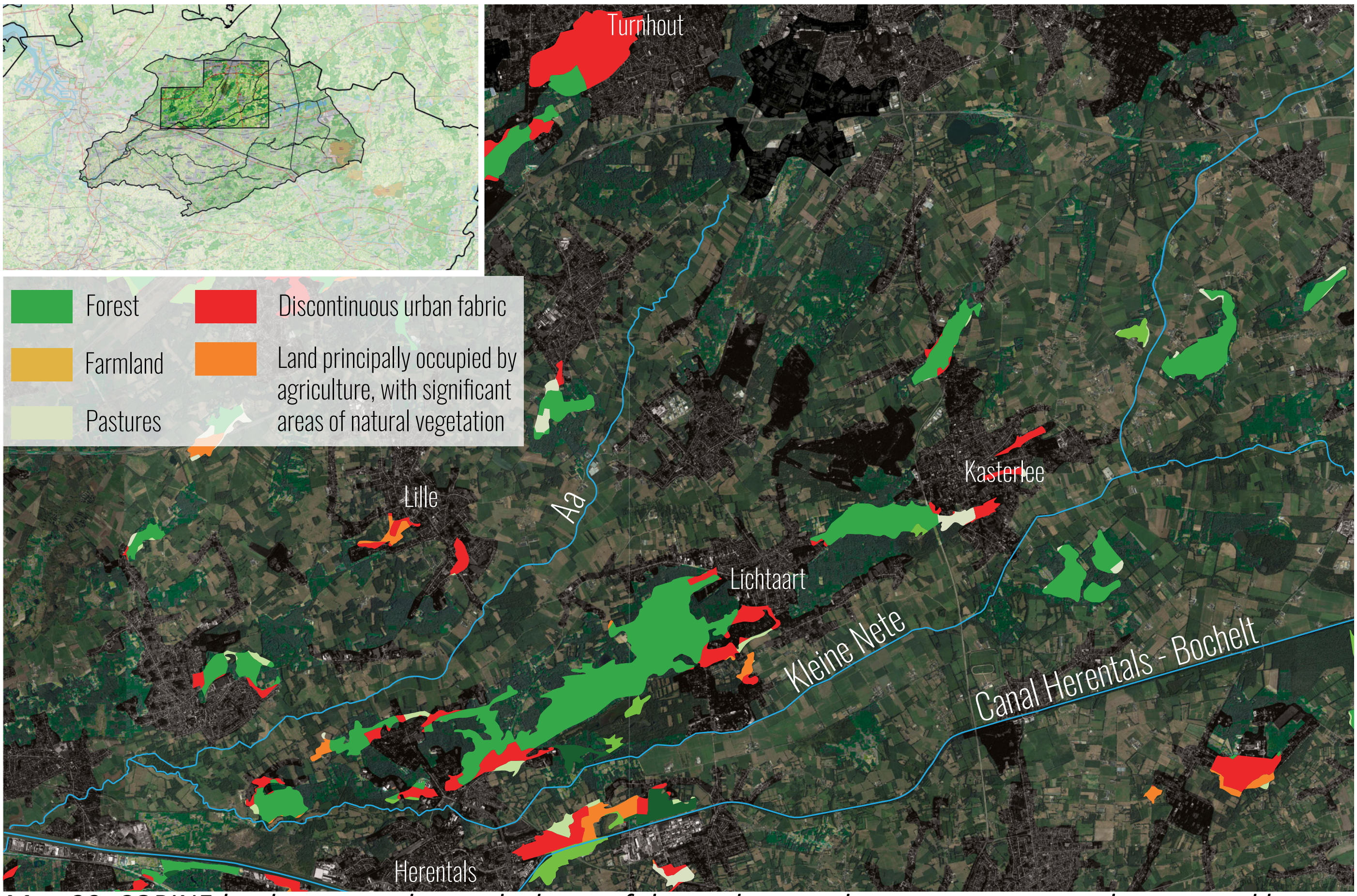
Sandy dunes are a particular type of elevated area in the landscape of the Campine region. Barren sandy dunes in the Campine region result from human-induced wind erosion (Vander Mijnsbrugge et al., 2012). Preindustrial population growth in Flanders led to vegetation removal due to agricultural expansion, overgrazing and removing the topsoil layer (***plaggen***) on the sandy plain in the Campine region. The resulting wind erosion on the barren sandy soils formed dune structure (Beerten et al., 2014; vander Mijnsbrugge et al., 2012). As a result, these dunes tended to drift and could cover pastures and farmland in their track. During the 18th and 19th centuries, spontaneous reforestation and pine replantation covered the sandy dunes resulting in soil fixation and reduced wind erosion processes on the sandy dunes. Gradually, the coniferous pine forest cover previously predominated native, primarily oak species on the sandy dunes due to the logging of oak tree species for household heating and the development of the mining industry in the eastern part of the Campine region required coniferous tree species. Beerten et al. (2014) state that "human disturbances [...] led to the complete reshaping of the interfluvium with severe soil erosion and the accumulation of drift sands in a deforested landscape dominated by heather vegetation and patches of bare land" (p. 11). When developing drought mitigation strategies to transform the sandy dunes' coniferous forests into heathland and deciduous tree species, these barren soil erosion processes should be considered. Different patches of sandy dunes are currently situated along the river Aa en Kleine Nete[2] (map 29).

The sandy dunes of the Nete basin are mainly covered by coniferous forests (map 30) and are a source of debate within various interest groups in the Campine region. Dewaelheyns & de Waegemaeker (2012) already noted the cultural identity associated with these coniferous forests. Additionally, most of these forests are ready for felling, thus making the authorities, nature, and forestry associations reflect on the future use of these areas (Foré et al., 2012). There are opposing approaches towards these pine forests, a more ecological oriented vision: planting indigenous trees, mainly oak, and an economic oriented vision: planting high-quality production trees, primarily pine. Regarding drought mitigation strategies, forest conversion could consider forest transformations into oak-birch forest or even heathland to increase the water infiltration potential.

2 The Chanal Herental – Bochtelt intersects the sandy dune east of Herentals (southern part of map 29), suggesting that the canal development did not consider the landscape morphology when developed. With canals, irrigation, tree plant ing and agricultural colonies, the 19th century government intended to cultivate the Campine regions heathland. Unem ployed farmers from East and West Flanders were imported for this purpose. "The project was not a success, but the canals and the trees does characterize the Campine landscape today" (van Acker, 2017, p. 1).

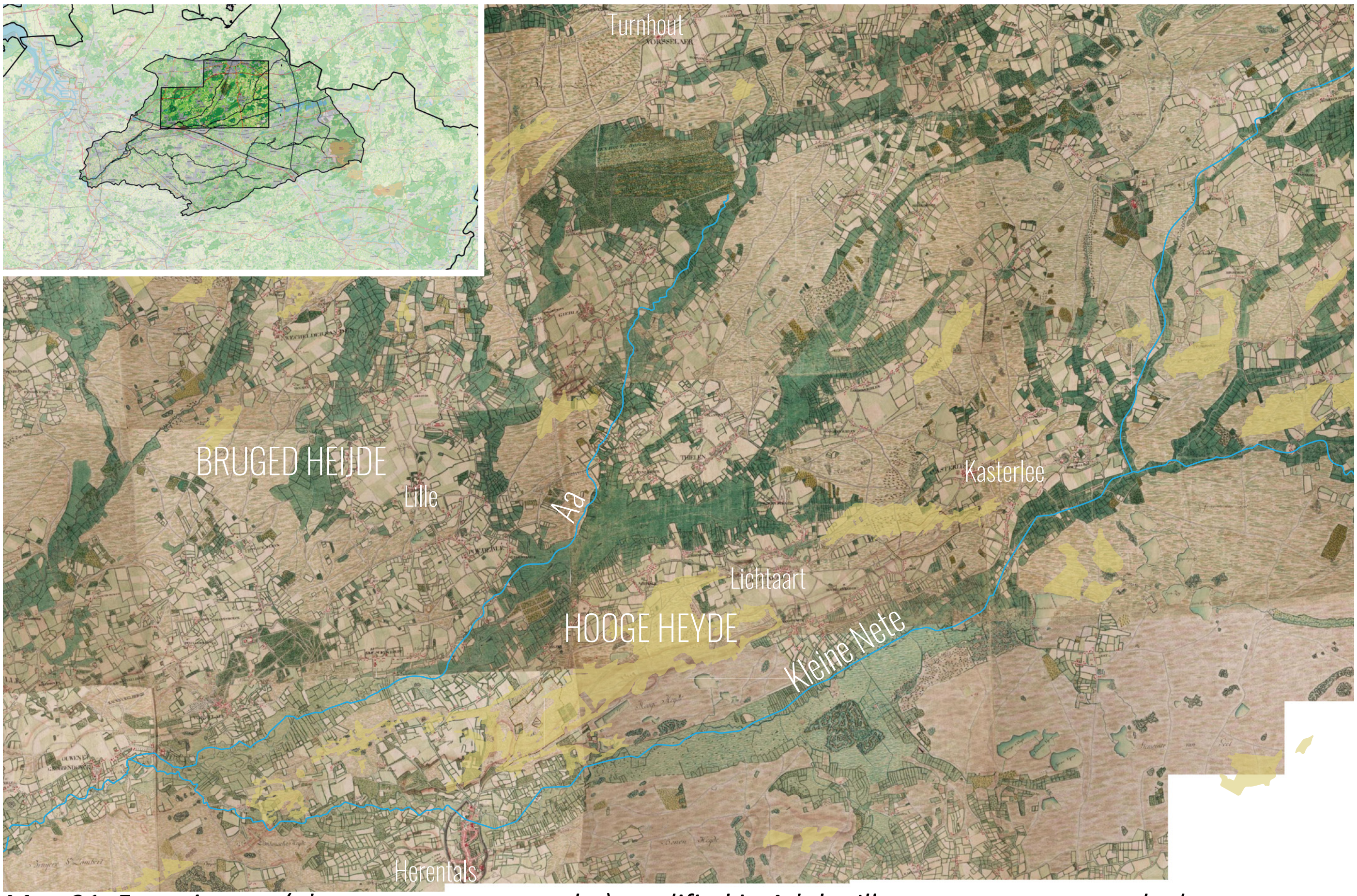


Map 29: sandy dunes along the Kleine Nete and Aa river. Data source: geopunt.be, Google Earth. Mapped by Sebastien Van Eupen

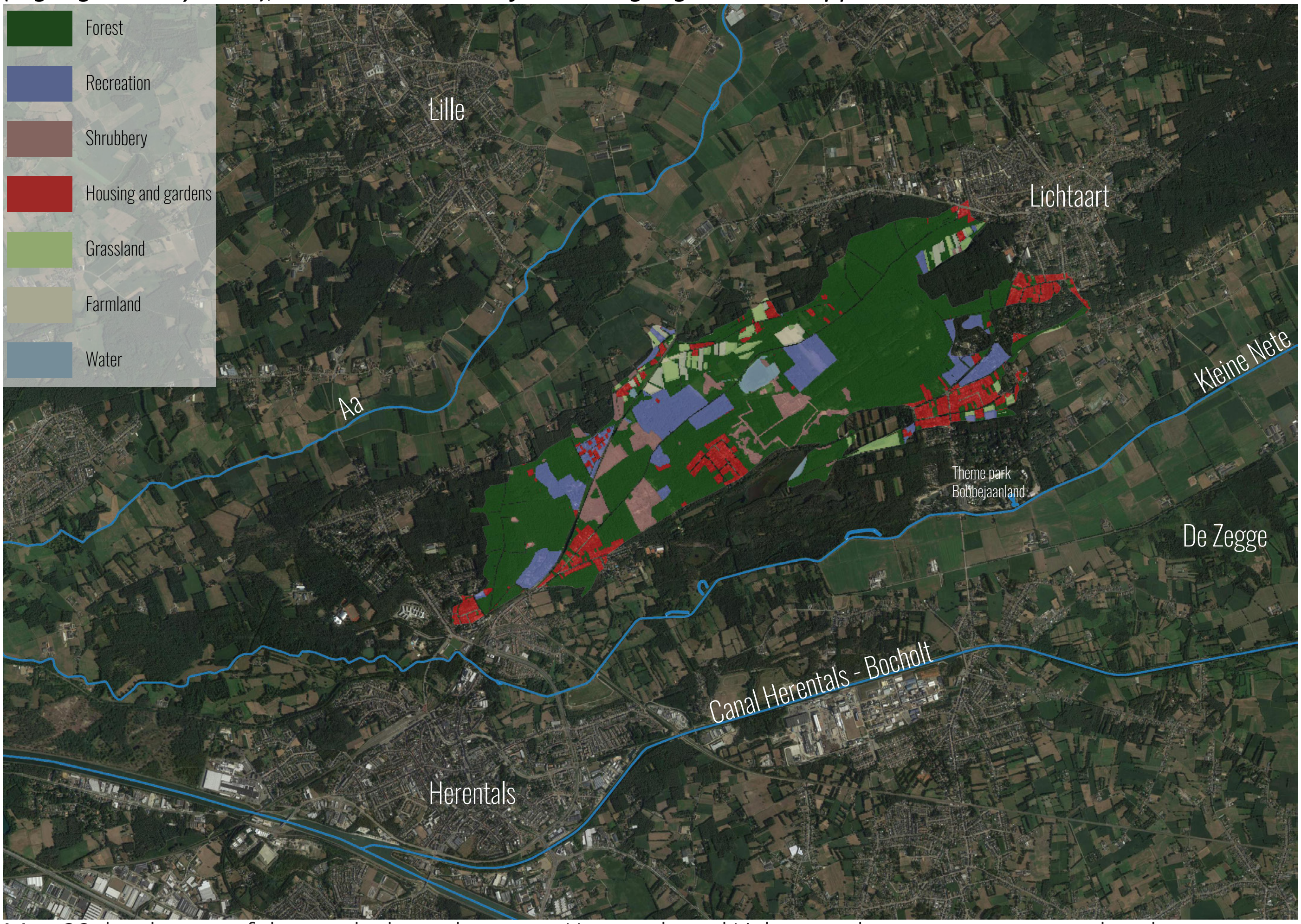


Map 30: CORINE-land cover on the sandy dunes of the study area, data source: geopunt.be, mapped by Sebastien Van Eupen.

Furthermore, coniferous forests and heathland are more susceptible to fire than deciduous trees. Historically, these land dunes were covered by heathland and extensive grasslands, as presented on the Ferraris map (map 31). Additionally, the toponomy of different place names on the Ferraris map (map 31) in the vicinity of some land dunes refers to heathland. The old Flemish words as 'Heyde' and 'Heijde' refer to heathland (Molemans, 1970). The Ferraris map notes the name ***Hooge Heyde*** on the sandy dune situated between the river Kleine Nete and Aa (map 31). The toponomy of this sandy dune, named Heiberg today, located between Lichtaart and Herentals suggests historical heathland cover. Currently, this area, called Heiberg today, is primarily covered by coniferous trees (map 30). Additionally, the present-day term "Heiberg" also relates to heathland. Map 32 presents the land cover on Heiberg in more detail. Shrubbery indicates the presence of wet and dry heathland.



Map 31: Ferraris map (data source: geopunt.be) modified in Adobe Illustrator, current sandy dunes (highlighted in yellow), heathland name reference highlighted with upper case



Map 32: land cover of the sandy dunes between Herentals and Lichtaart, datasource: geopunt.be, departement omgeving (2019). Mapped by Sebastien Van Eupen

Agentschap voor Natuur en Bos (2014) presents management plans as a policy instrument to develop nature-related goals of the Natura 2000-policy. For example, management plan BE2100026 (2014) shows the demarcated zone with objectives 2310_2330 and 4010_7150 in the west on map 33. These codes translate into goals to develop a natural land cover dominated by dry heathland on the elevated areas and wet heathland in the lower-lying area near the Kleine Nete. Some patches of heathland are currently present on the Heiberg, a nature reserve of 60 ha (Decock, 2021). This is the result of nature restoration projects managed by the NGO Natuurpunt. Natuurpunt has been working for about ten years to create a “mosaic of different habitats, with a variety of heathland and woodland” (Natuurherstel in Heiberg-Snepkensvijver | Natuurpunt, n.d.).

Natuurpunt strategically felt pine trees and sodded the soil to create and restore heathland (Decock, 2021; Natuurherstel in Heiberg-Snepkensvijver | Natuurpunt, n.d.). Sheep grazing on the Heiberg helps maintain the heathland vegetation. Additionally, Natuurpunt converts different areas between heathland patches and pine trees into deciduous forest patches, mainly oak trees. 2,5 ha of pine trees transformed into heathland, a European target habitat (Decock, 2021). As a result, the coniferous–heathland conversion on the Heiberg resulted in a 46% decrease of intercepted water[3] (graph 2). Additionally, graph 3 presents the yearly average groundwater resupply resulting from infiltration. Grassland, shrubland and heathland contribute twice as much as mixed coniferous forest to the groundwater supply. Therefore, the coniferous-heathland conversion on Heiberg significantly contributed to drought mitigation strategies and EU biodiversity Natura 2000 goals on the porous sandy soils of Heiberg[4].

Steas et al. (2020) additionally note that forest-heathland conversion negatively impacts erosion prevention and lowers to C-storage content of the soil. These aspects should be considered in the decision-making process. Nonetheless, the nature restoration project of Natuurpunt on the Heiberg complements the drought mitigation strategies proposed by Foré et al. (2012).

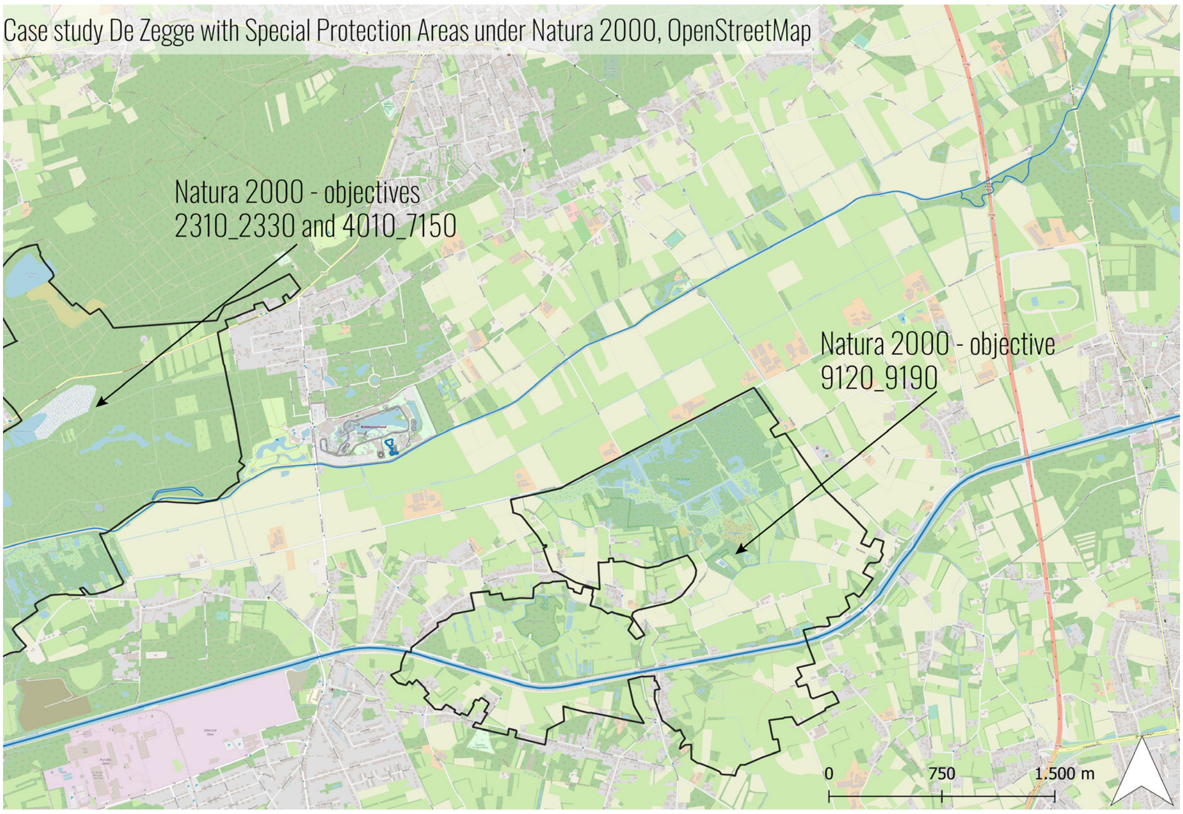
The Spatial Vision for Agriculture, Nature and forests – Nete Region (Ruimtelijke Visie Voor Landbouw, Natuur En Bos Regio Neteland - Operationeel Uitvoeringsprogramma) (2007) indicates that a Regional Spatial Implementation Plan (GRUP) should be developed for “strengthening the nature values on the Campine sandy dune in the broad surroundings of the nature reserve around Snepkensvijver [on the Heiberg]”. Currently, a GRUP is being developed for the valley systems north and south of the sandy dune presented on map 32. This will be further elaborated in section 4.2.2.2.1.

Foré et al. (2012) note that the transformation of land dunes needs to be subjected to a well-thought-out transformation process from coniferous to deciduous forests and heathlands. So that the landscape identity can co-evolve with the ‘new’ landscape, therefore, an overall vision for the Campine land dunes could be appropriate. Heathland restoration, in combination with deciduous oak tree forests on the sandy dunes, could be a promising landscape development path, as heathland and deciduous tree enhance water infiltration (Staes et al., 2020; van Hoydonck et al., 2001) and thus contribute to groundwater level inflows, resulting

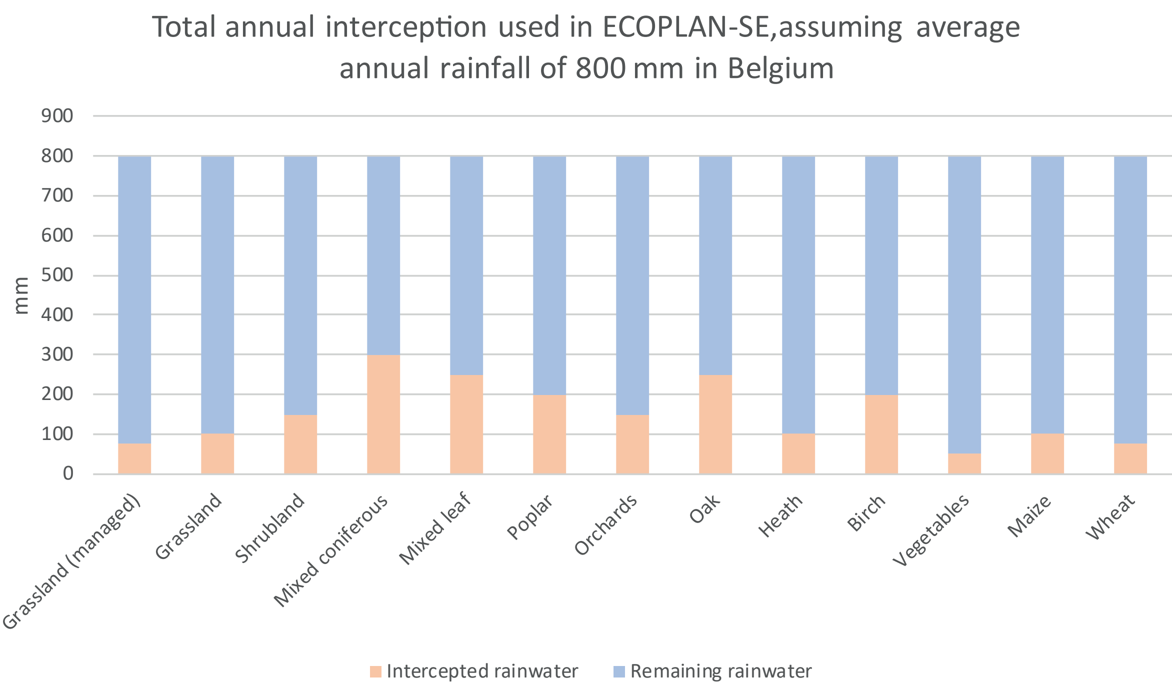
3 Rain can be intercepted by vegetation and evaporated directly from the canopy or indirectly via transpiration back into the atmosphere.

4 Water retention and infiltration effects depend on the type of soil. Forest cover and interception have a positive drought reducing effect on heavy soils (e.g. clayey soils in West-Flanders), as they buffer extreme precipitation events and promotes infiltration. In contrast, forest covering sandy soils, in general, reduce infiltration (Staes et al., 2020).

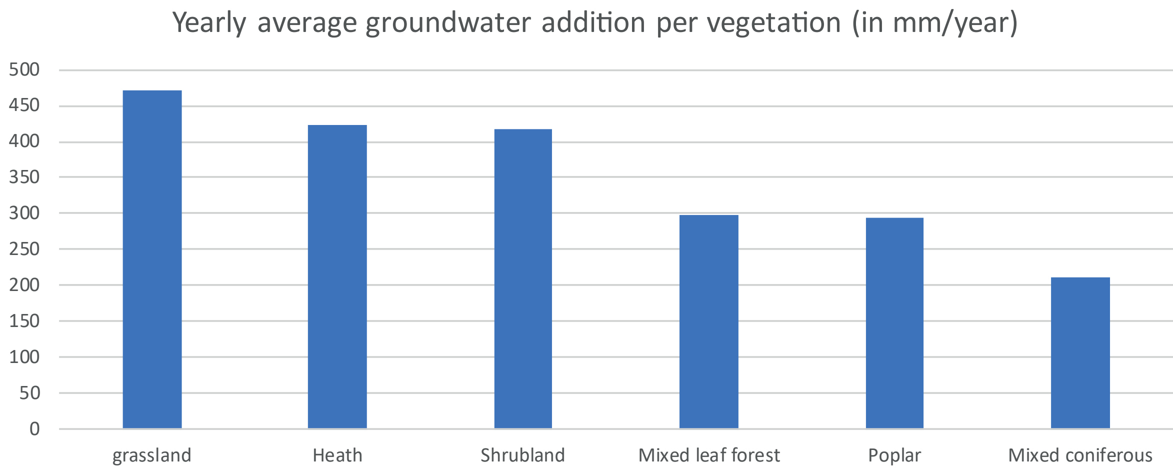
Map 33: Natura 2000 areas on the Heiberg and De Zegge, data source: geopunt.be



Graph 2: data derived from Staes et al. (2020).



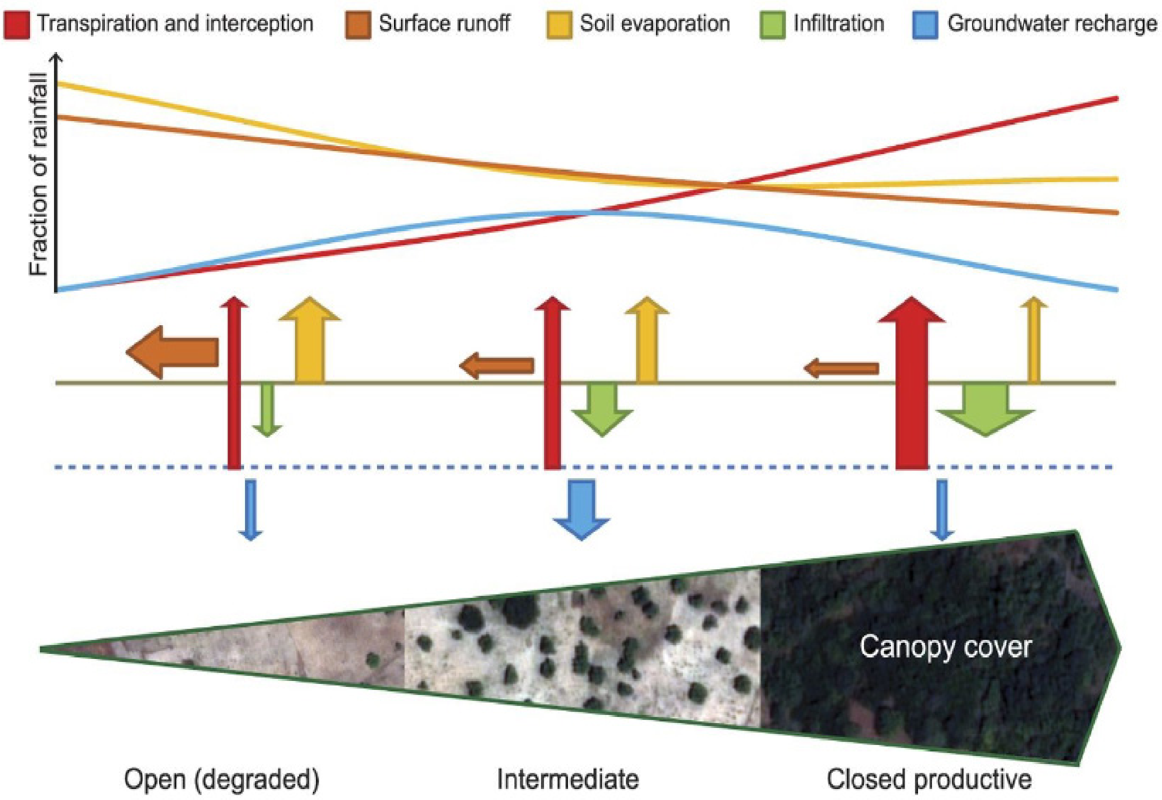
Graph 3: data derived from Staes (2018).

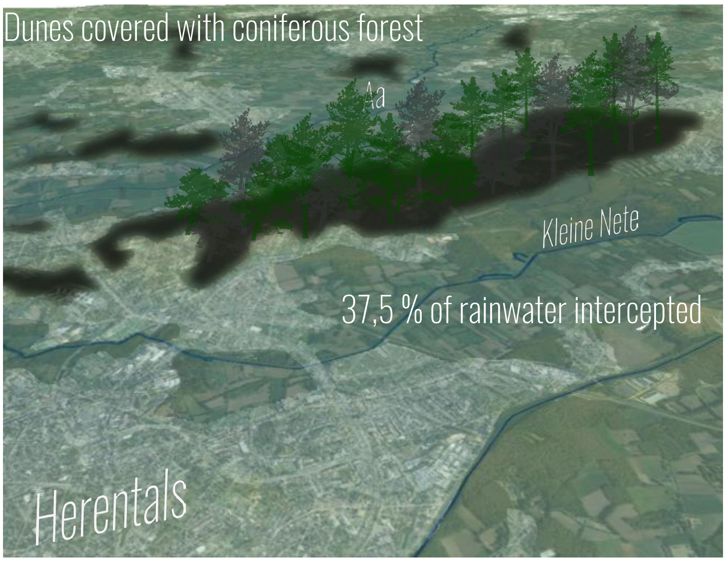


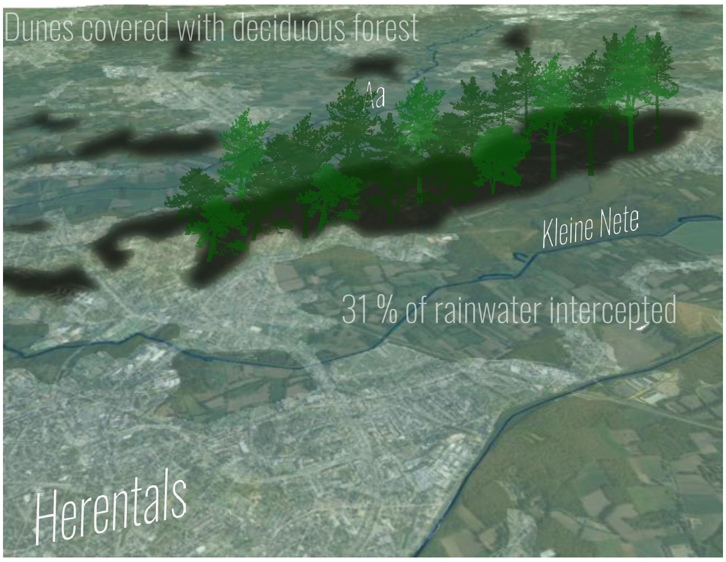
in an increased drought resilience of the Campine region and, to a larger extent, Flanders. Another aspect to take into account regarding water infiltration is the optimal tree cover density. Trees enhance infiltration but also limit groundwater recharge through interception and transpiration. Ilstedt et al. (2016) presented an optimum tree cover theory whereby an intermediate tree density maximizes groundwater recharge (figure 9).

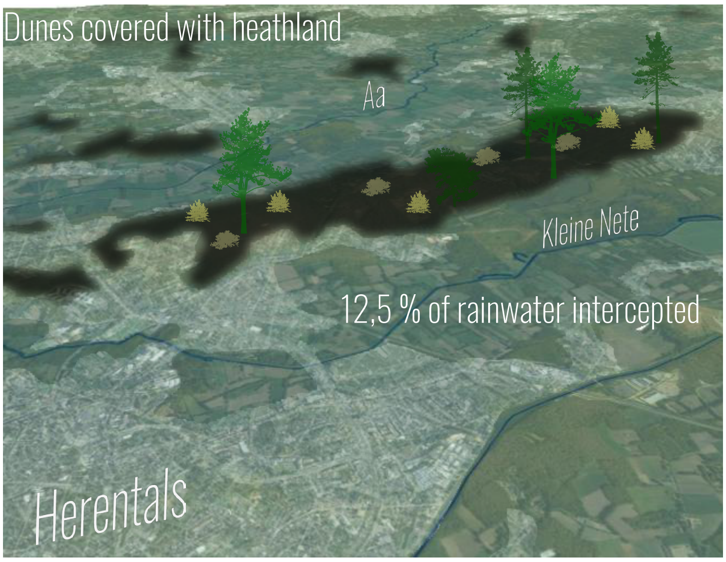
Additionally, landscape development processes should be thoughtful of barren soil formation during transformation processes due to soil erosion risks (Beerten et al., 2014). The NGO Natuurpunt improved the water infiltration capacity of the sandy dune Heiberg. This case's planning, and landscape development process could provide a blueprint for implementing drought mitigating strategies on other sandy dunes in the Campine region. A similar, more minor scale case is the fen and heathland restoration in Grobbendonk (*Grobbendonk (BE) - Prowater*, n.d.). The cases of Heiberg and Grobbendonk are embedded in the European pilot drought planning research project PROWATER ('Protecting and Restoring raw water sources through actions at the landscape scale'). The results of this research will project will be published in 2022.

Figure 9: Illustration of the optimum tree cover theory (Ilstedt et al., 2016).




Dunes covered with coniferous forest
Aa
Kleine Nete
37,5 % of rainwater intercepted
Herentals


Dunes covered with deciduous forest
Aa
Kleine Nete
31 % of rainwater intercepted
Herentals


Dunes covered with heathland
Aa
Kleine Nete
12,5 % of rainwater intercepted
Herentals

4.2.2.2 Wetland restoration in the Nete basin: reducing drainage discharge to increase the Nete's buffer capacity, De Zegge as a case study

Historically, the Campine region's landscape is characterized by a mosaic of landscape elements (Foré et al., 2012). This region was not well suited for agriculture as the sandy soil on elevated areas is prone to drought, and the porous soil texture created wet conditions in valleys. Therefore, the water system of the Campine region underwent radical transformations to improve agricultural efficiency by draining wetlands and providing irrigation water for drier land with rivers and canals. In order to facilitate agriculture in the wetter valleys, a system of small canals for water drainage was implemented parallel to the rivers (Dewaelheyns & Foré, 2012). Due to climate change, drainage in the wetter winter months combined with irrigation in the drier summer month shall be increasingly needed. In addition, increased soil sealing resulted in a reduction of the water buffering and retaining potential of the Nete basin. The NGO Natuurpunt (Verbelen, 2019) and policy such as the Habitat Directive and VEN-areas (de Sutter et al., 2012; Foré et al., 2012) aim to develop blue-green structures for both the Nete rivers to counter this problem.

The Nature Report 2020 recommends restoring ecosystems' natural hydrology by raising surface water systems' drainage levels (Schneiders et al., 2020). This could be done by filling or decreasing the depth of drainage ditches or remeandering rivers. The drought strategy designs of Foré et al. (2012) of the river Grote Nete consider removing the water drainage infrastructures such as the siphons and drainage canals in historically wetter areas. Consequently, upstream regions will experience a higher average soil moisture content due to downstream discharge reduction. In this scenario, existing agriculture shall have to adapt to wetter conditions or implement large scale drainage systems with pumps. However, the latter would partially undermine the initial reason for removing drainage infrastructure and siphons, indicating that wetting the landscape would not be compatible with current agricultural practices.

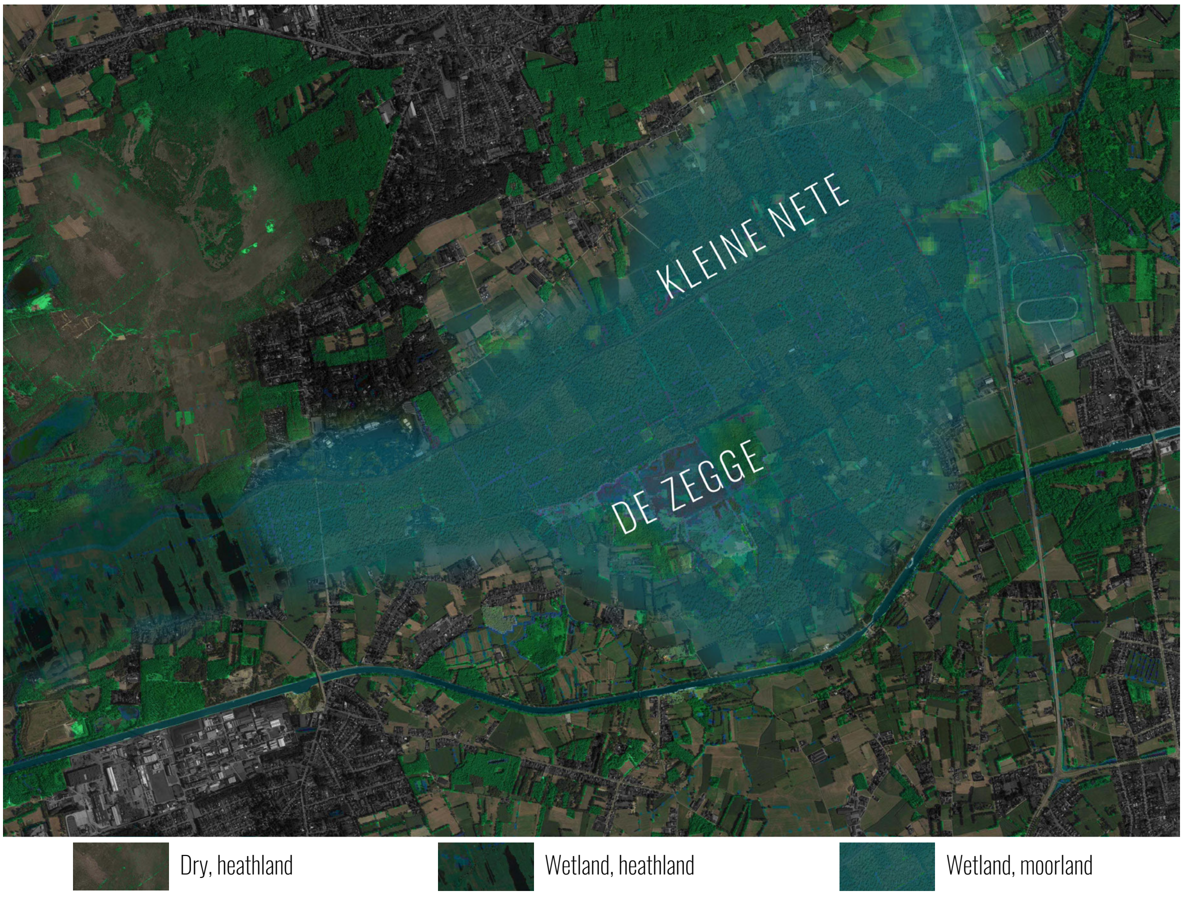
As a case study, this thesis examines a similar situation along the Kleine Nete. The nature area, called De Zegge, is a wetland situated near the Kleine Nete (map 34). In 1958 the peat wetland areas along the Kleine Nete were drained, parcelled out, and developed as agricultural land, except De Zegge (Verhoestraete & Staes, 2019). The nature reserve of De Zegge is one of the oldest ones in Belgium. Antwerps Provincial Governor, Cathy Berx, mentioned that the nature reserve De Zegge has to be sustained and strengthened from an increasing drought problem (GVA, 2021).

The space between De Zegge and the Kleine Nete presents a potential for wetland development. Currently, agriculture is the primary occupant of this area. The potential wettening of the landscape can co-inside with the European Natura 2000-policy translated into the demarcated Special Protection Zones on map 33 (section 4.2.2.1.2). The indicated codes of Natura 2000-goals in the demarcated Special Protection Zone in the centre of map 33 translate into wetland conditions. To a limited extent, a wetland is present in the central area of the demarcated Special Protection Zone. This area is called De Zegge.

As mentioned in section 4.2.2.1, wetland areas have a relatively high infiltration potential (van Hoydonck et al., 2001). In addition, wetland characterizes by a relatively high water retention potential (Foré et al., 2012; Kersbergen et al., 2020). Insights from Hoydonck et al. (2012), Foré et al. (2012) and Natura 2000-policy goals form the basis for the wetland development presented on map 35.

Map 34: aerial view of De Zegge and surrounding areas. Forest is highlighted in green; housing, gardens and recreational areas are highlighted in grey.

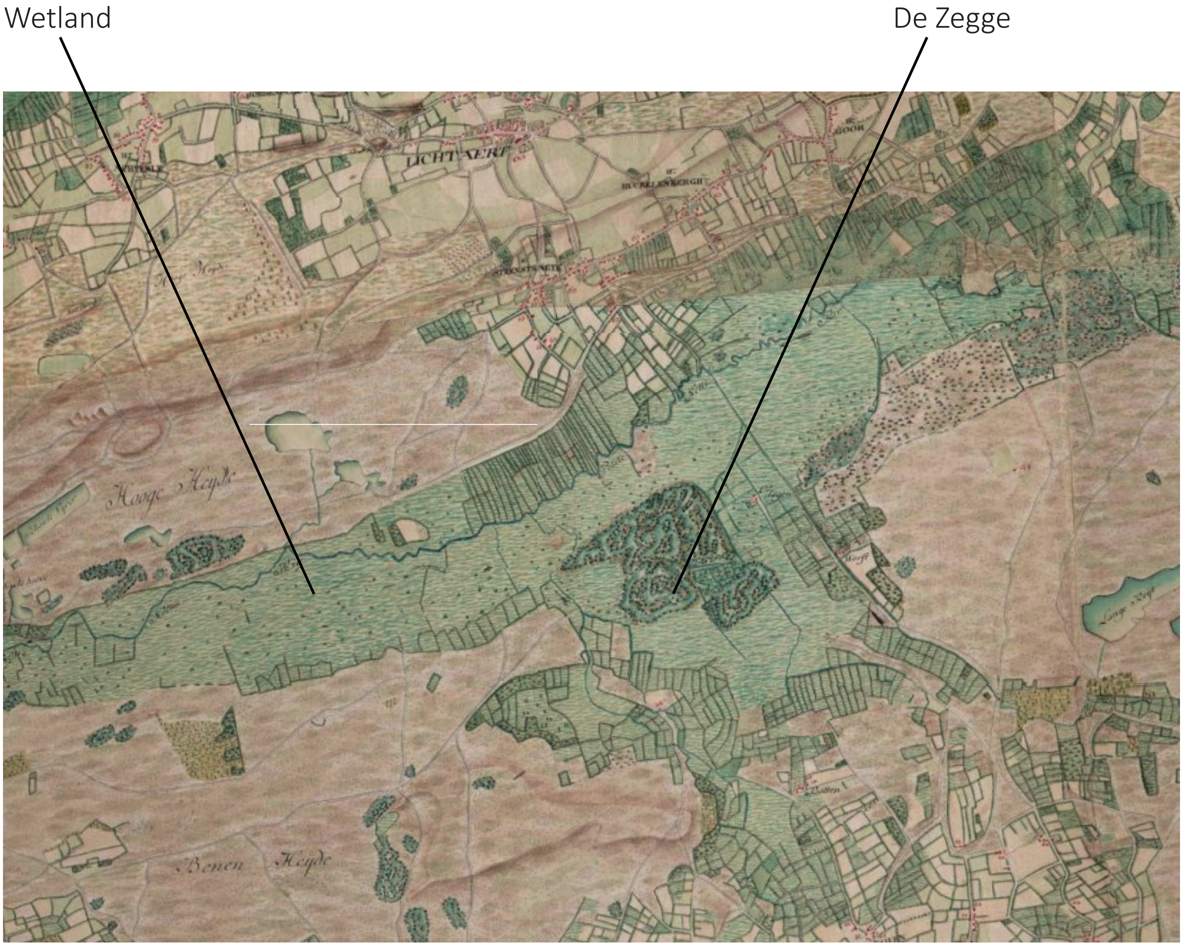
Map 35: delineation of potential wetland development near De Zegge and the Kleine Nete river



Through GIS analysis, the potential development of wetland on map 35 was delineated from a DEM (Digital Elevation Model). A flow direction raster[5] (figure 10) was extracted from the DEM data. The black line presents the accumulation of flow directions and thus shows the natural pathway of the Klein Nete without dikes and other structuring mechanisms holding the position of the Kleine Nete in its current course. This also explains the series of small canals (map 36) and pumping systems (Opvolgingscommissie Kleine Nete, 2020) that provide a drainage function for the agricultural parcels, as this area's soil is prone to oversaturation of water.

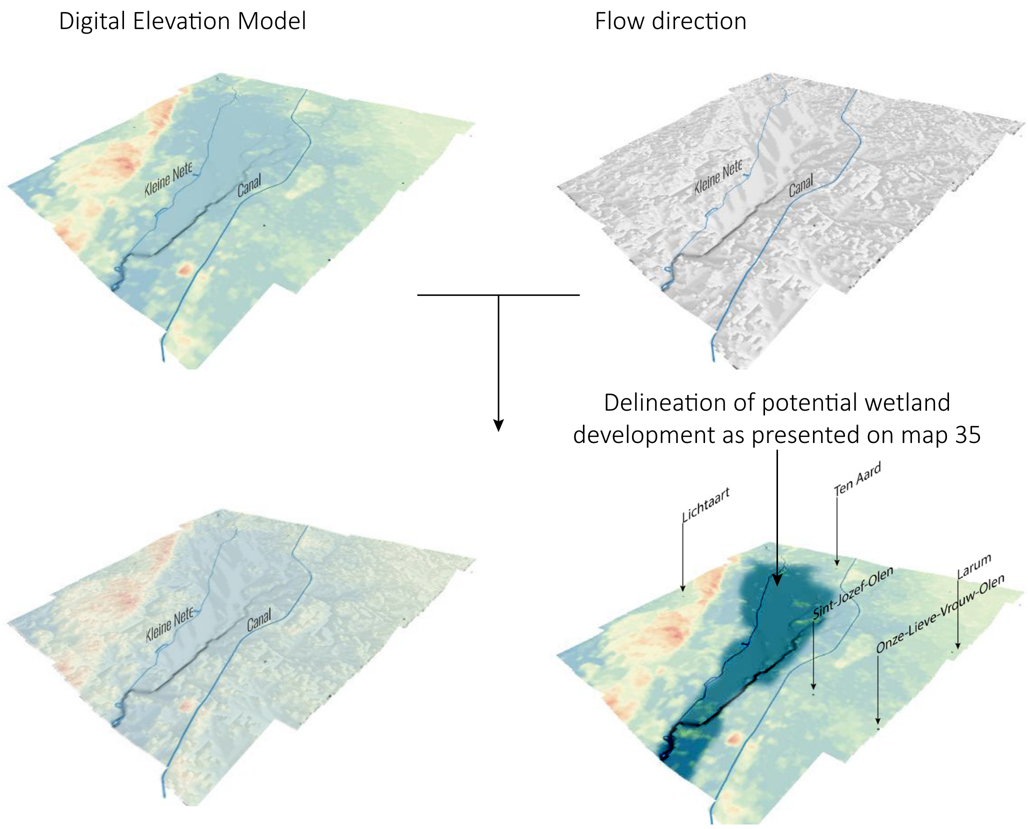
Different arguments can be presented as a case for the development of a wetland area between De Zegge and the river of the Kleine Nete demarked on map 35: (1) the present Natura 2000-goals could be further developed (Agentschap voor Natuur en Bos, 2014); (2) historically this area was a wetland area (Ferraris map 37) and thus restoring the wetland could fit in the morphology of the valley system; (3) the water retention and infiltration potential would improve significantly (Waterloo et al., 2019); (4) flood risks for the downstream region could be reduced (Kersbergen et al., 2020).

5 The flow direction raster presents the preferential pathway of rainwater runoff regarding the elevation differences in the landscape.



Map 37: Ferraris map of De Zegge and Kleine Nete river, source: geopunt.be

Figure 10: DEM (top left) and flow direction raster (top right) of the area around De Zegge



Map 36: The small drainage canals between De Zegge and Kleine Nete river, data source: OpenStreet-Map, mapped by Sebastien Van Eupen

Additionally, the Regional Implementation Plan Kleine Nete (GRUP Kleine Nete) states that in the agricultural area north of De Zegge, the groundwater level is permanently more than 60 cm below surface level due to agricultural drainage canals and pumping (Departement Omgeving, 2021). "This has major consequences for the nature area [De Zegge]" (Departement Omgeving, 2021, p. 113). The agricultural drainage activities resulted in the shrinkage of the peat soil under the farmland (Verhoestraete & Staes, 2019). As a result, the agricultural land surrounding De Zegge lies approximately 1,5 m lower than De Zegge itself. As a consequence, the significant differences in water level within a short distance create a hydrostatic pressure difference (Departement Omgeving, 2021). As a result, groundwater flows from the Zegge towards the farmland between De Zegge and Kleine Nete river. The drainage canals are situated two meters below De Zegge. There, excess water is pumped and drained towards the Kleine Nete river. This causes an almost permanent water shortage in the nature reserve of De Zegge, especially during the summer half-year. A pumping system pumps some drained water back towards De Zegge, but this "measure is increasingly ineffective and, according to experts, the Zegge is doomed if no urgent action is taken" (Verhoestraete & Staes, 2019, p.4). As a consequence, the nature area is slowly declining if no action is undertaken.

Currently, no housing and gardens are present in the potential new wetland area (figure 11). Therefore, a rewetting of the valley system could be fitted into the built-up area of the neighbouring municipalities (figure 12). However, in this scenario, existing intensive agricultural practices would not be able to co-exist with the newly restored wetland. Verhoeven & Setter (2010) state that the "extensive use of wetlands without drastic reclamation measures and without fertilizer and pesticides might result in combinations of food production with other wetland services, with biodiversity remaining more or less intact" (p. 6). The current agricultural land along the Nete river contains drainage channels to lower the soil moisture content to produce consistent crop yield (Dewaelheyns & Foré, 2012). Wetland restoration measures would increase the soil moisture content, in contrast to current intensive agricultural practices, which aim to lower soil moisture content. Therefore, current farming practices must be reevaluated, thoroughly adapted or removed from the area to restore the wetland in this scenario.

Collective action by citizens, local actors, and NGOs contributing to the public interest could develop these areas' green and blue network potentials. Developing alternative agricultural practices such as community-supported agriculture (Landwehr et al., 2021) or increasing the recreational potential of the site (Buijs et al., 2018) are examples of ways to improve local engagement. Yu et al. (2018) present a more radical shift by suggesting diversification of agricultural practices from an exclusively production-focused approach to wetland recreational agriculture, where agricultural activities (e.g. agroforestry, agro-gardening and wetland-supported animal husbandry) are used for recreation.

Nonetheless, there are examples of extensive farming practices in wetlands in South-East Asia and Sub-Sahara Africa, where local communities produce food primarily for their own family or village (Verhoeven & Setter, 2010). "In such cases, natural wetlands are used for agricultural production without complete reclamation, leaving the natural hydrological processes partly intact. Such systems do not necessarily lead to complete loss of the other regulating and supporting wetland functions and services [including biodiversity]" (Verhoeven & Setter, 2010, p. 7). Therefore, wetland restoration around Kleine Nete presents significant challenges. Wetland farming systems should be optimized, leaving the wetland hydrology intact and protecting

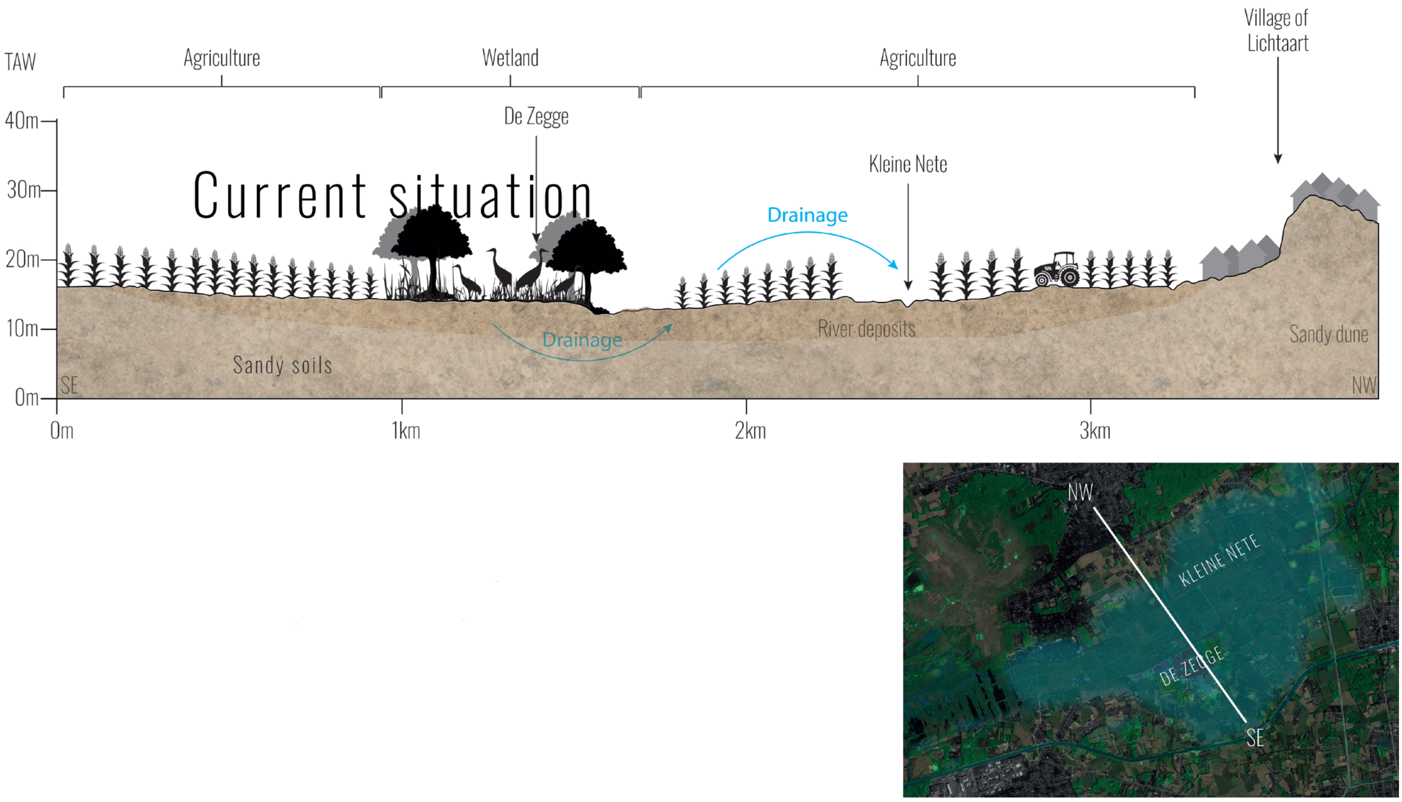


Figure 11: NW-SE cross-section of the current land-use situation between De Zegge and Kleine Nete, developed by Sebastien Van Eupen, templates (trees, birds, vegetation templates sourced from vecteezy.com)

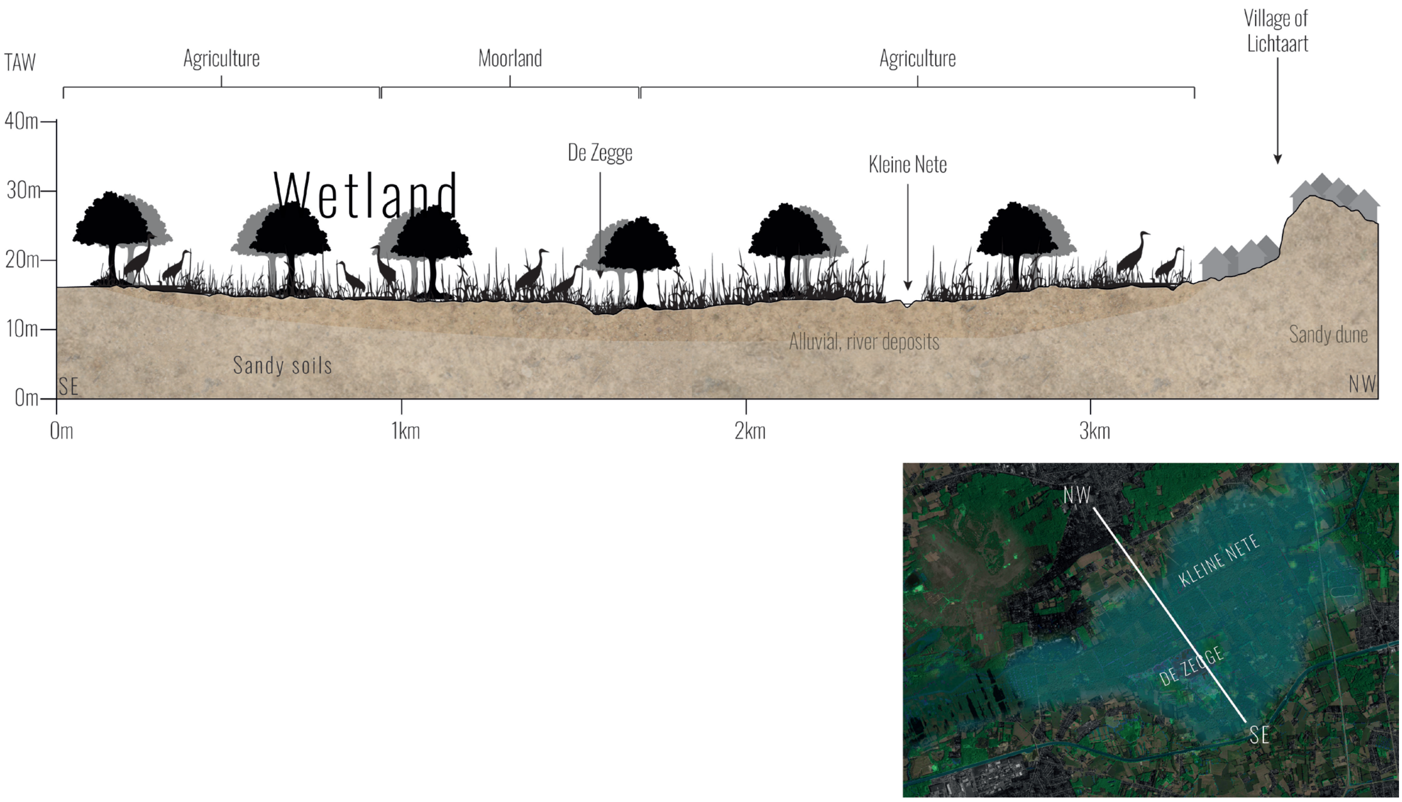


Figure 12: NW-SE cross-section of the potential new wetland situation between De Zegge and Kleine Nete, developed by Sebastien Van Eupen, templates (trees, birds, vegetation templates sourced from vecteezy.com)

its water-retaining and biodiversity functions as much as possible. The Ferraris map, presenting the historical condition, and the GIS analysis, showing the natural pathway of the Kleine Nete, do provide a delineation of this new wetland area.

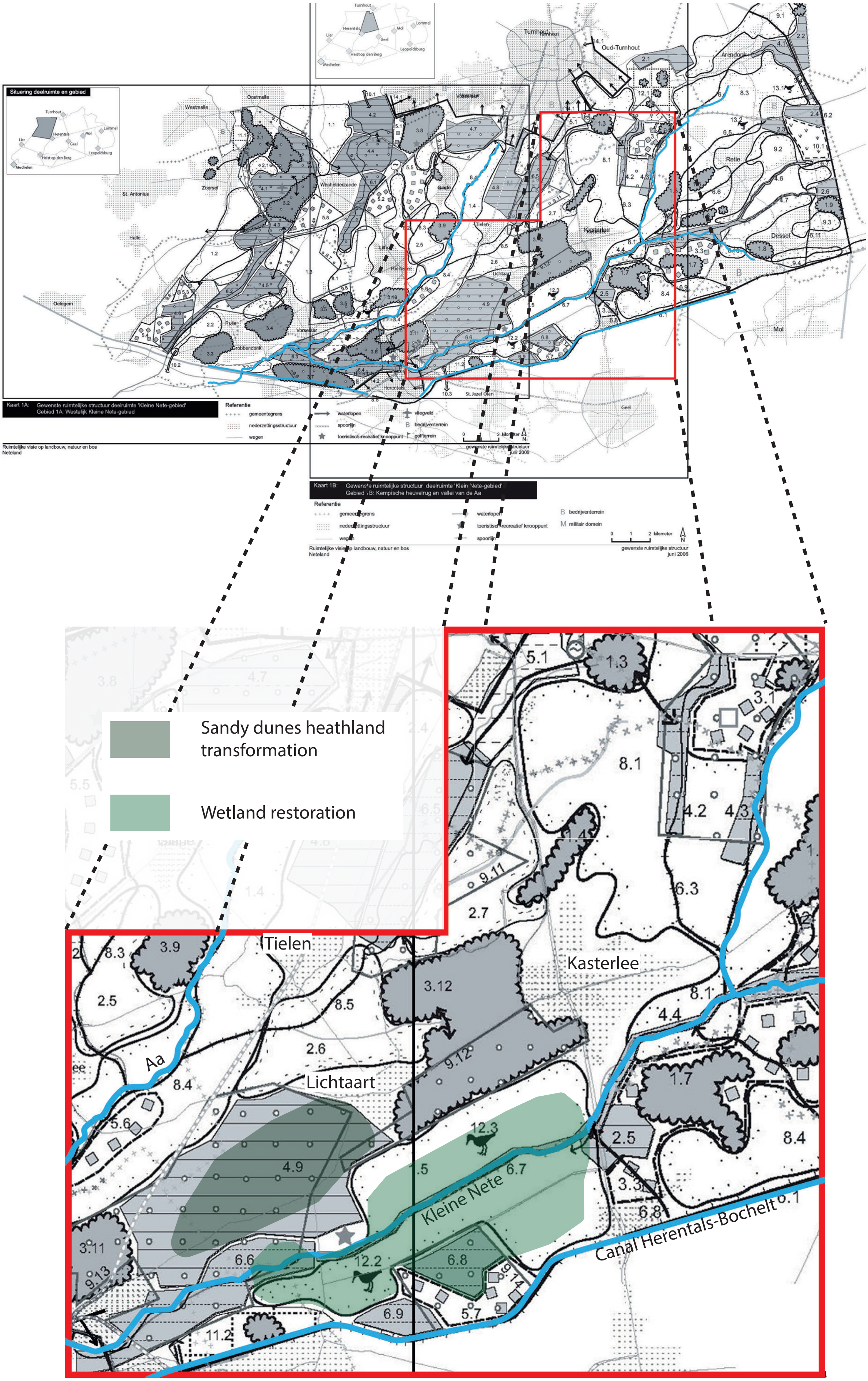
Currently, Verhoestraete & Staes (2019) are researching how to potentially develop the valley of the Kleine Nete into a National Peatpark. In this vision, the agricultural drainage activities would be phased out. The new wetland reactivates the peat layers and would increase the soil's water retention capacity. Additionally, Verhoestrate & Staes (2019) propose removing Kleine Nete's dike structure and reducing the river course's depth so that the river would restructure throughout the whole valley. Nevertheless, spatial planners would have to develop thorough stakeholder analyses and strategies to include farmers as one of the most significant stakeholders in potential wetland restoration projects.

4.2.2.2.1 Potential spatial policy basis for a rewetted valley system near De Zegge

Map 38 presents the envisioned spatial structure from the spatial vision document Neteland (2007). Three structure plans were combined in Adobe Illustrator, and the area of interest for the drought strategy concepts in the scope of this thesis is highlighted and enlarged with a red polygon.

The structure plan Neteland (2007) presents different visions for different areas indicated with a number on the map. For example, 1.5 indicates a reaffirmation of agricultural areas: the confirmation of the Regional Zoning Plan (***gewestplan***) for a contiguous agricultural area in the valley of the Kleine Nete. Although, the Neteland structure plan (2007) does present long-term visions aiming to diversify the agricultural function of this area. The plan indicates to "strengthen the natural values in the valley of the Kleine Nete between Herentals and Kastelee [6.7, map 38] and around the nature reserves De Zegge and Mosselgoren [6.6, 6.7, 6.8 and 6.9 map 38], and aim for differentiation of the area south of de Zegge as a spatially interwoven agricultural area, nature enhancement area, nature, green or woodland area and/or forest area (5.7)" (Ruimtelijke Visie Voor Landbouw, Natuur En Bos Regio Neteland - Operationeel Uitvoeringsprogramma, 2007, p. 8). Additionally, the draft of the Nete basin management plan 2022-2027 states that the recent dry summers highlighted the drought situation in the valley system of the Klein Nete. "Concerning Olens Broek [west of De Zegge, indicated with 11.2 on map 38] and De Zegge nature reserve, in particular, the involved parties should undertake to investigate, with the necessary objectivity, whether additional measures are needed to prevent and combat drought in Olens Broek and the De Zegge nature reserve. An essential precondition is that a balance is found with the area's current, actual agricultural use" (Ontwerp Stroomgebiedbeheerplannen Schelde En Maas 2022-2027, 2021, p. 69).

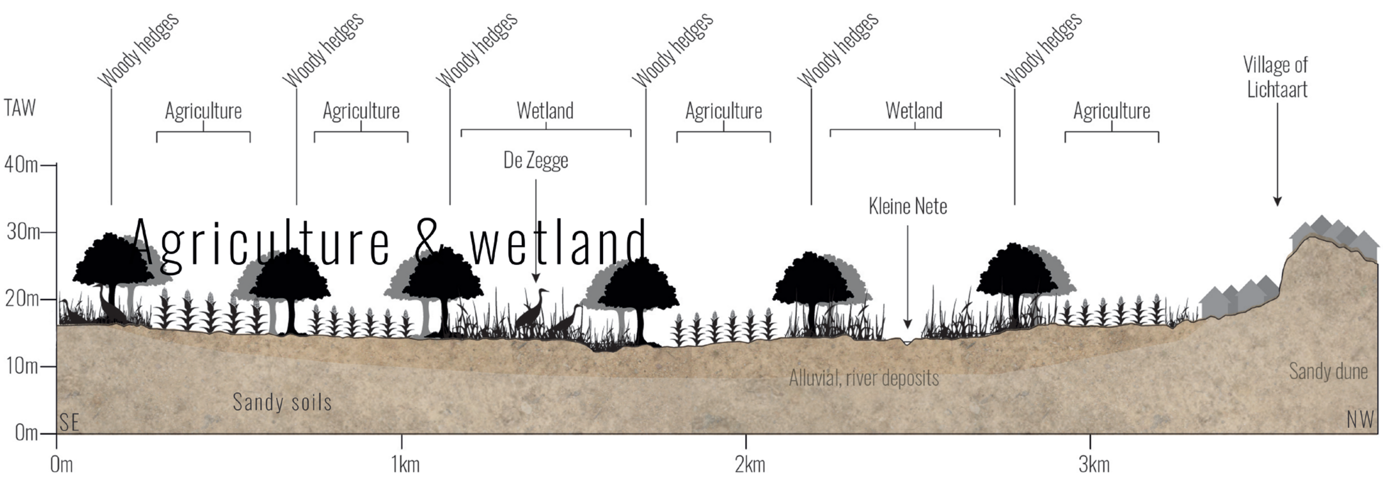
Map 38: structure plans of the area near De Zegge (Neteland, 2007).



Additionally, current farming practices near De Zegge nature reserve, and by extent, Flanders' valley systems, will very likely experience increasing risks of flooding due to climate change in the 21st century (Tabari et al., 2015). The area near De Zegge is already indicated as an effective flood-prone area, and the adjacent land is marked as a potential flood-prone area (Vlaamse Milieumaatschappij, 2017) (map 39) presenting an additional argument for wetland restoration.

The Structure Plan Neteland (2007) suggest a spatial compromise should be pursued. A complete shift in this area from agricultural parcels to an extensive and biodiverse wetland is not supported by the structure plan (2007) by reaffirming the existing agricultural area (1.5). However, the structure plan indicates strengthening the natural value in the valley system (6.7). Thus, less intensive farming practices (e.g. agroforestry, pastures,...) and wetland features could potentially present a pragmatic solution (figure 13). Researchers such as (Marty, 2005; Tesauro, 2001) indicate the biodiversity benefits from cattle grazing toward invasive exotic vegetation as long as grazing intensity is managed sustainably (Limpert et al., 2021). This thesis will not further discuss the details of this wetland grazing regime.

However, the preliminary draft of the Regional Spatial Implementation Plan Kleine Nete (GRUP Kleine Nete) presents a different approach (Departement Omgeving, 2021). The proposed destinations are shown on map 40. The plan aims to preserve the agricultural area and safeguard the undeveloped, unbuilt character of the flood-prone parts of the Kleine Nete valley. Although, the preliminary draft of GRUP Kleine Nete does mention the compromising effect of agricultural drainage activities on the natural functions of De Zegge.



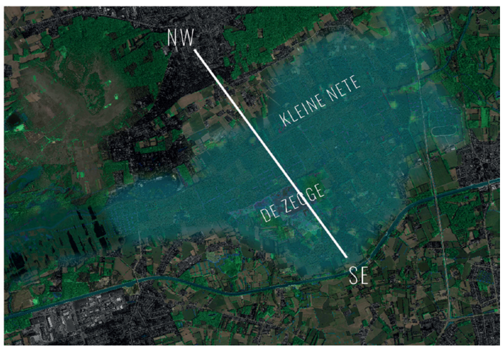
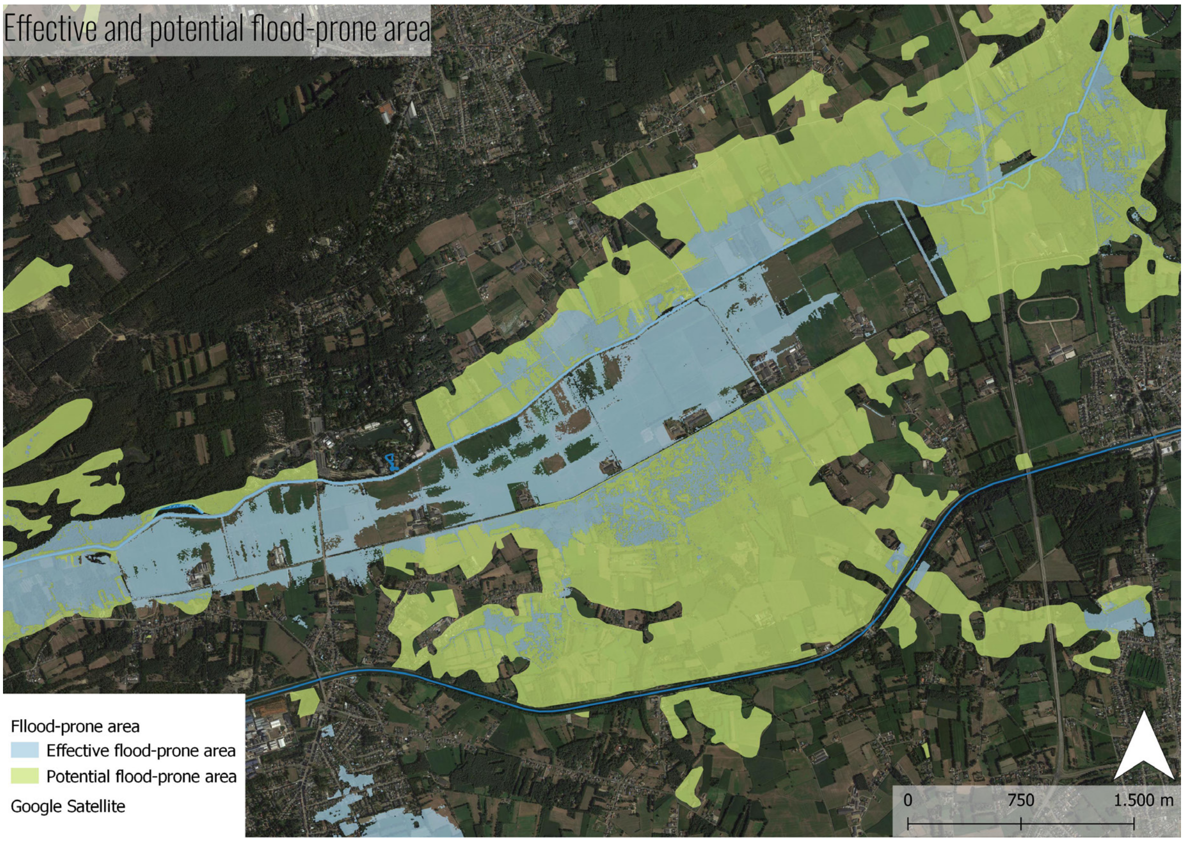
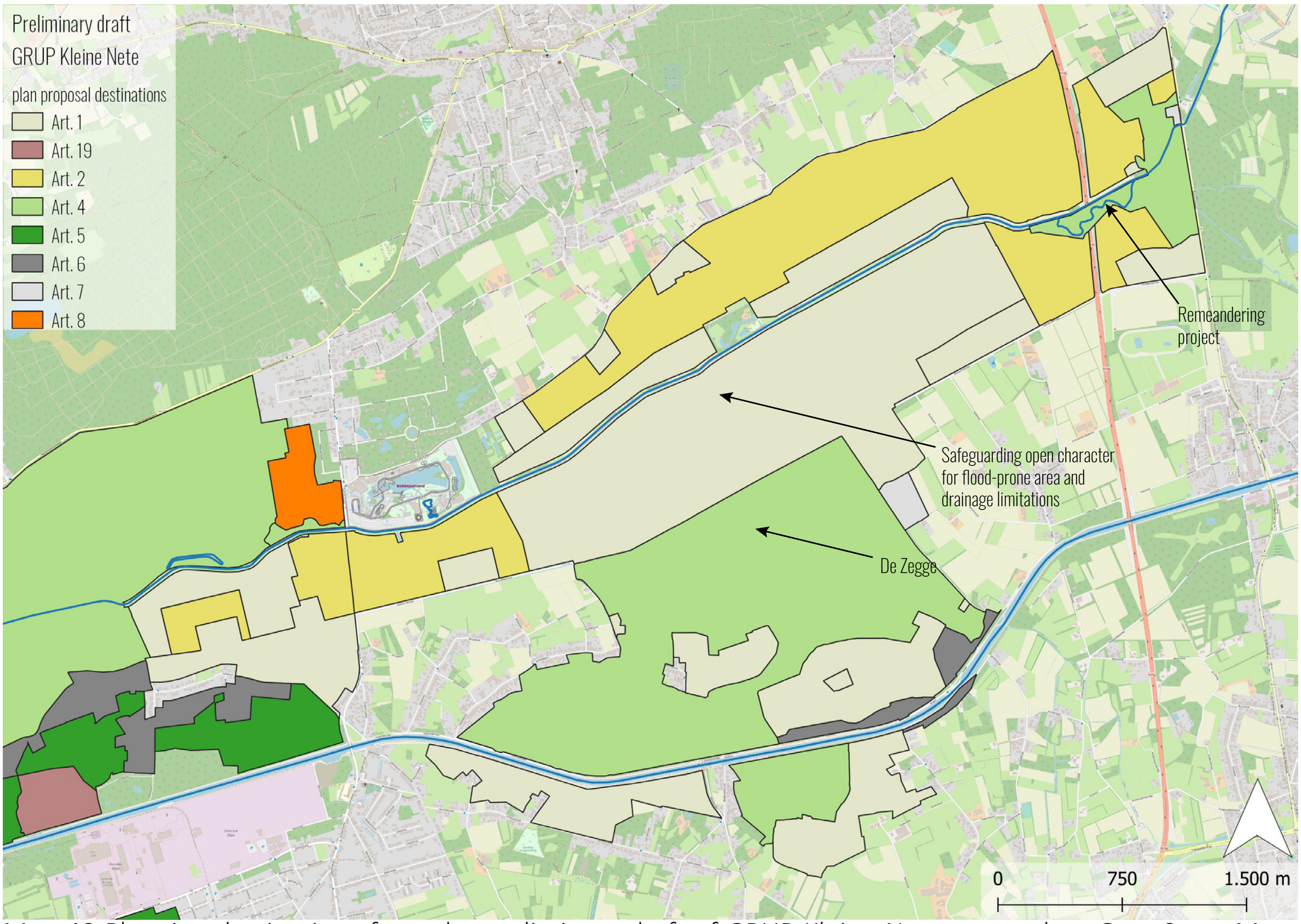


Figure 13: NW-SE cross-section of a combination of wetland and an agricultural land-use situation between De Zegge and Kleine Nete, developed by Sebastien Van Eupen (trees, birds, vegetation templates sourced from vecteezy.com)

Map 39: effective and potential flood-prone area near De Zegge nature reserve. Datasource: geopunt.be, mapped by Sebastien Van Eupen





Map 40 Planning destinations from the preliminary draft of GRUP Kleine Nete mapped on OpenStreetMap-layer, data source: geopunt.be, mapped by Sebastien Van Eupen

The GRUP Kleine Nete proposes "boundary conditions [that] are imposed on water level management in function of agriculture: [future] actions or interventions in the area that are aimed at changing the groundwater levels in the valley area are only allowed in so far as they do not undermine the conservation (preservation and restoration) of the natural values in the adjoining bird and habitat directive areas and do not cause further drying of the underlying peat layers and soil subsidence" (Departement Omgeving, 2021, p. 113). This proposition aims to lower the impact of agricultural drainage on groundwater levels in the neighbouring Natura 2000 areas and therefore proposes that all actions aimed at changing the groundwater level will have to be subjected to an appropriate assessment (***passende beoordeling***).

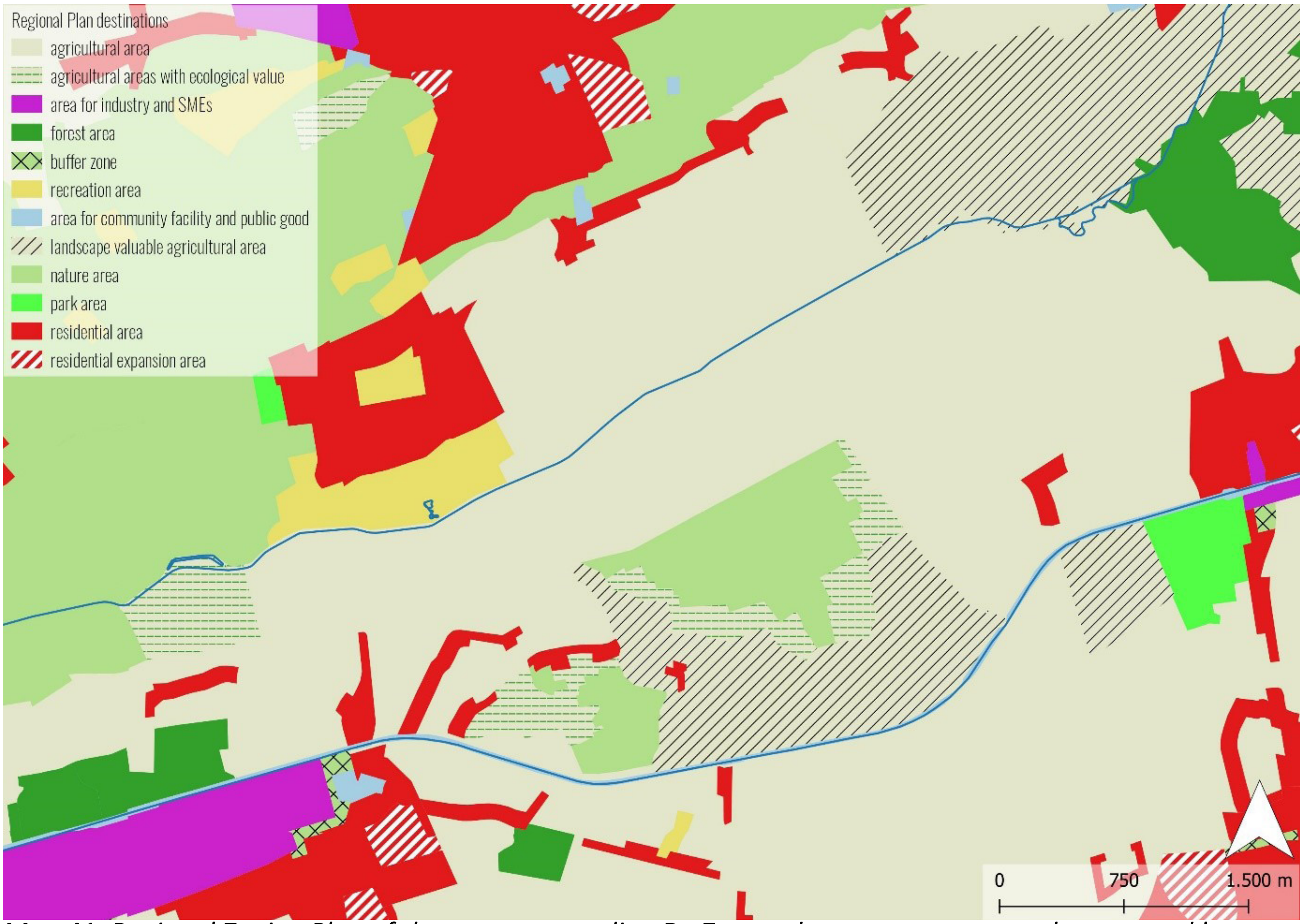
> "Moreover, in order to meet the Natura 2000 targets, it is likely that part of the agricultural area in the valley of the Kleine Nete just north of the nature reserves De Zegge [...] need to be effectively turned into a wetland, unless other technical solutions are found to counteract the drying of the Natura 2000 area [De Zegge]. If it should prove necessary (based on the results of the ongoing ecohydrological study) to wet the area north of De Zegge, this will probably mean that the agricultural activities in the area cannot be continued in their present form" (Departement Omgeving, 2021, p. 114).

On the Regional Zoning Plan (***gewestplan,*** map 41), the agricultural area surrounding De Zegge, the 'agricultural areas with ecological importance' are already included in the Flemish Ecological Network delineation reallocated to nature area (Art. 4, map 40). In the east, the N19 was constructed. Near the crossing with the Kleine Nete, a re-meandering project is planned as nature compensation.

The current propositions of the GRUP Kleine Nete suggest a wetland restoration could be desirable from a biodiversity perspective and additionally a drought mitigation perspective. However, these suggestions are not yet materialized on the preliminary draft's proposed destinations. The area between De Zegge and Kleine Nete embeds drainage limitation propositions in the GRUP Kleine Nete, but these would be insufficient to fully develop the area's natural and drought mitigating function. Perhaps the reallocation of agricultural land between De Zegge and Kleine Nete would be a preferable spatial planning strategy (Verhoestraete & Staes, 2019).

On the other hand, the preliminary draft of the River Basin Management 2022 – 2027 of the Nete basin state that regarding "the De Zegge nature reserve, the parties involved are committed to investigating, with the necessary objectivity, whether additional measures are needed to counteract drought in the De Zegge nature reserve. An important precondition is to find a balance with the current, actual agricultural use in the area" (CIW, 2020, p. 69).

The objective of finding a balance between nature-based drought mitigation strategies and current agricultural practices near De Zegge does unravel a reoccurring spatial conflict between an agricultural productivity perspective and environmental and climate change mitigation perspective, as illustrated in the start-up memo (***procesnota)*** of the GRUP Klein Nete. Public participation in the start-up memo set out various interests concerning the planning destinations of the GRUP Kleine Nete (Departement Omgeving, 2019). For example, the GRUP proposes to transfer specific parcels from the category nature area, which are located in VEN, towards an agricultural area with ecological importance. The environmental assessment and the VEN-test will show if this transfer is possible. Different stakeholders have expressed different approaches toward these parcels. The Farmers League (***Boerenbond***) and individual farmers have



Map 41: Regional Zoning Plan of the area surrounding De Zegge, data source: geopunt.be, mapped by Sebastien Van Eupen

stated their vision to designate the parcels as common agricultural areas. In contrast, the NGO Natuurpunt opts to keep the nature area intact. Additionally, the preliminary Environmental Impact Report (***ontwerp-MER***) indicated that transfers of these parcels from nature to agricultural areas would compromise the groundwater quality (van Elst, 2021). Therefore, the demand of the Farmers League and individual farmers will probably not be granted in the definitive GRUP. Additionally, figure 14 presents these conflicting perspectives on agricultural land between farmers and nature conservation actors based on the actor reactions noted in the process nota of the preliminary draft of GRUP Kleine Nete.

This example showcases the agricultural stakeholders whose interests often does not coincide with nature development goals. Nevertheless, as mentioned in section 4.2.2.1.1, the agricultural sector plays a crucial role in developing spatial drought strategies in the Nete basin.

The Flemish governmental investment plan Flemish Resilience ***(Vlaamse Veerkracht)*** (Monitoring Relanceplan Vlaamse Veerkracht - Voortgangsrapport En Covernota - Meetmoment December 2021, 2021) does provide 23 million euros for flagship-projects with nature-based solutions to improve infiltration, soil water retention and water storage in and around waterways. The investment plan refers to a "number of m² of acquired project and/or exchanged land in function of the realisation of wet nature objectives SBZ-H [Natura 2000 area]" (2021, p. 202). Currently, draft decisions and refunding policies are being developed. The financial support of this plan could potentially provide a stimulus or negotiation basis for the potential development of a rewetted valley system near De Zegge. Verhoestraete & Staes (2019) state that the cost to compensate 400 ha of agricultural land for nature area would outweigh the renewed wetland's benefits as a water buffer. A new wetland of 400 ha would store 4 million m³ of water. As a result, the base river flow of the Klein Nete could increase by 0,5 – 0,75 m³/s at Herentals, increasing water availability of downstream agriculture and reducing the extent and amount of groundwater extraction bans during drought period. Additionally, by connecting a potential wetland with the existing nature area of the Heiberg, a new nature area of 2400 ha would "provide unprecedented recreational possibilities" (Verhoestraete & Staes, 2019, p. 4).

There is still much potential for wetland development in the Nete basin. Map 42 presents the urban fabric (in red) and flat areas surrounded by relatively elevated areas with slopes converging into these flat areas (in grey). These flat areas were derived from GIS analysis and only considered elevation to delineate potential wetland development. Nevertheless, this analysis concludes that 26% of the Nete basin area consists of these flat areas, indicating the considerable potential for wetland development in the Nete basin. To complete, the wetland concept discussed in the scope of this thesis, marked on map 42 with a black ellipse, contains one of the largest areas for potential wetland development in the Nete basin.

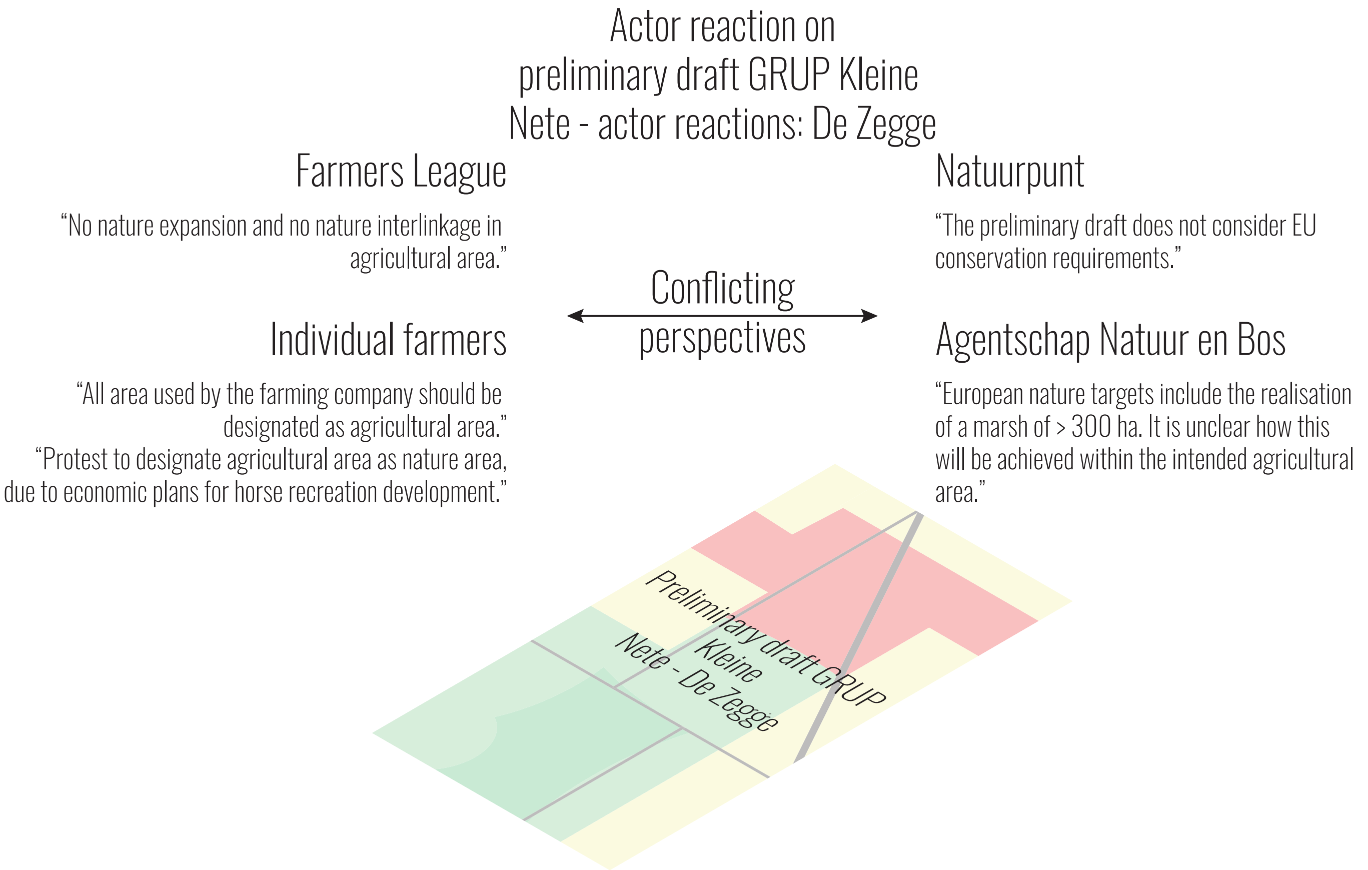
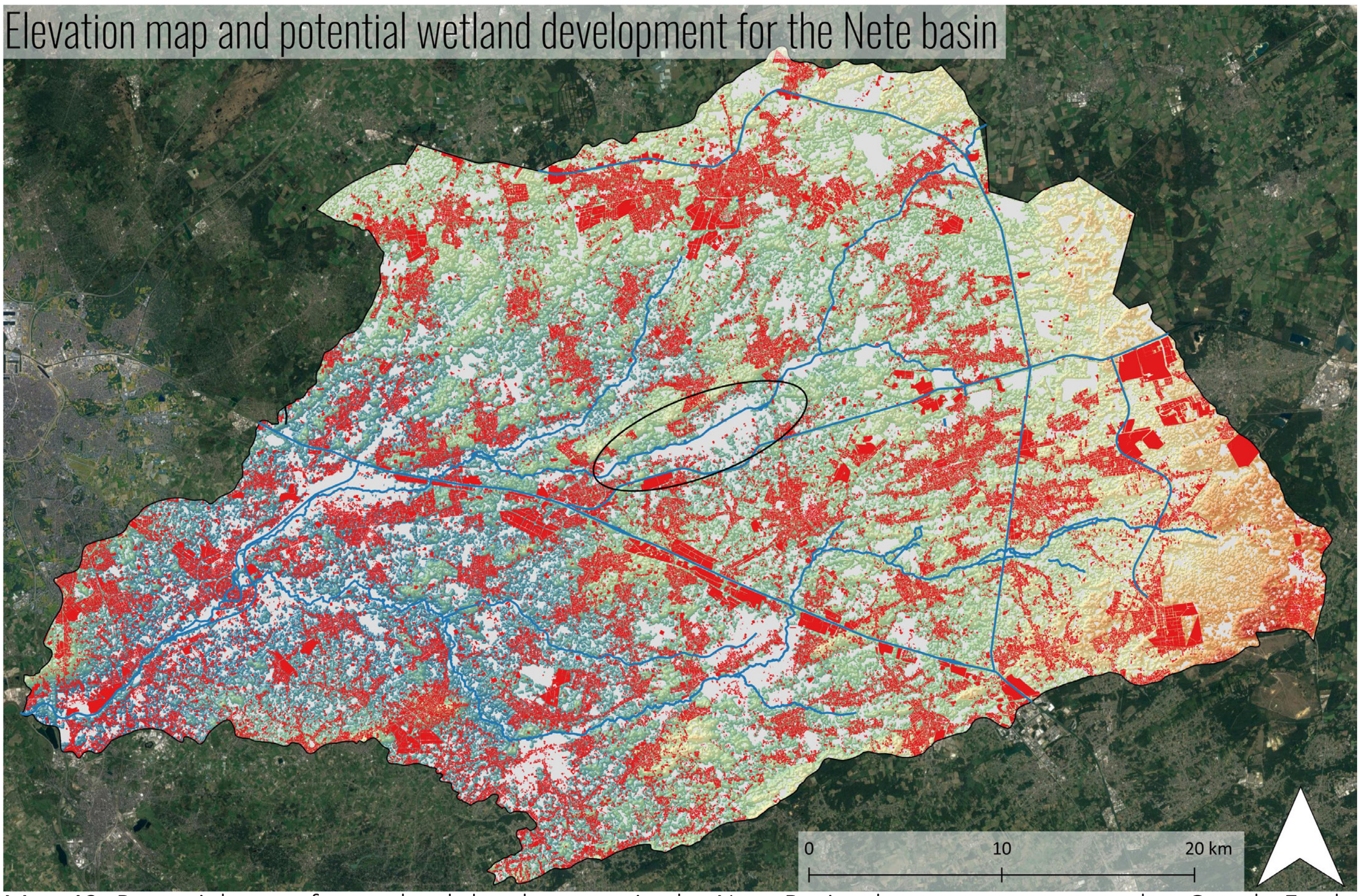


Figure 14: illustrative scheme showcasing the conflicting perspectives of different actors on the preliminary draft of GRUP Kleine Nete, De Zegge, developed by Sebastien Van Eupen



Map 42: Potential areas for wetland development in the Nete Basin, data source: geopunt.be, Google Earth, analysis and mapping by Sebastien Van Eupen

4.2.2.3 Increasing drought resilience with gardens

84% of dwellings in Flanders have a garden, which covers 9% of Flanders' area (Dewaelheyns & van Rompuy, 2019). Goddard et al. (2010) state "that gardens are not to be viewed as separate entities at the individual scale, but instead managed collectively as interconnected patches or networks of green space acting at multiple spatial scales across the urban landscape" (p. 6). The patchwork of individual gardens can be seen as an integral and structuring component of the landscape. "The key to this lies in the aggregation of individual private gardens into the 'garden complex' (Dewaelheyns & van Rompuy, 2019, p. 16). The garden complex is an ensemble of private gardens in a neighbourhood, city, and region. This spatial perspective on gardens shifts the focus from an individual garden perspective toward an approach where gardens are seen as elements in the landscape. The combination of all 'tiny, individual' decisions in gardens has a 'significant environmental impact' (Dewaelheyns & van Rompuy, 2019; Goddard et al., 2010). Individual garden decisions regarding soil sealing and vegetation type impact drought. (e.g. on average, 1/3 of the garden area is sealed (Dewaelheyns & van Rompuy, 2019)). The garden complex embeds a lot of water infiltration potential in Flanders but mobilising these potentials forms a challenge (Foré et al., 2012). In contrast to dwellings, few planning regulations (***voorschriften van stedenbouwkundige verordeningenen en RUP's***) apply to gardens (Dewaelheyns & van Rompuy, 2019). This translates into diverse garden characteristics. Some initiatives in Flanders do demonstrate the possibility of mobilising private gardens for collective purposes, such as water infiltration. The initiative Curiezeneuzen monitored soil temperature and moisture content of more than 5000 gardens in Flanders between March 2021 and October 2021 (Curieuzeneuzen, 2022). The Curieuzeneuzen-project (2022) reports that gardens with sandy soils retain 20% more water than clayey soils, indicating the relative high drought strategy potential for gardens in the Nete basin. Additionally, western and northern oriented gardens retain 20% more water than eastern and southern oriented gardens. Initiatives such as Curieuzeneuzen (2022) and Tuinlab (2022) suggest reducing soil sealing and increasing biodiversity as a measure to increase the moisture-retaining potentials of gardens.

Nonetheless, garden strategies to mitigate drought forms a whole new research project. Therefore, the supposedly considerable potential of spatial drought strategies with private gardens is not further investigated in the scope of this thesis.

4. CONCLUSION

Historically, spatial planning practices delineated nature areas as residual areas, which were economically unprofitable. Therefore, ecological hotspots, e.g. gradient areas and wetlands, were rarely designated as natural areas in a spatial plan. However, "there is an urgent need for a new conceptual framework that is no longer based on the planological delimitation of functions, but on the specification of area-specific environmental conditions based on underlying physical processes" (Verhoestraete & Staes, 2019). This thesis attempted to start from these underlying physical processes to develop drought strategies in the Nete basin, first considering the land cover, hydrology and landscape geomorphology before considering area-specific spatial planning policy. The developed drought strategies were subjected to existing spatial plans and plans under development to assess if the current and developing spatial planning policies could facilitate the implementation of the developed drought strategies in the Nete basin. A potential wetland development near De Zegge would prove to be challenging due to opposing stakeholder perspectives. But the effect of recent spatial planning policy on drought mitigation strategies will still have to be determined. Several policy documents and reports, such as the Blue Deal, Spatial Policy Plan of Flanders, PROWATER and drought and rainwater plans, set out significant planning strategies for drought mitigation in Flanders.

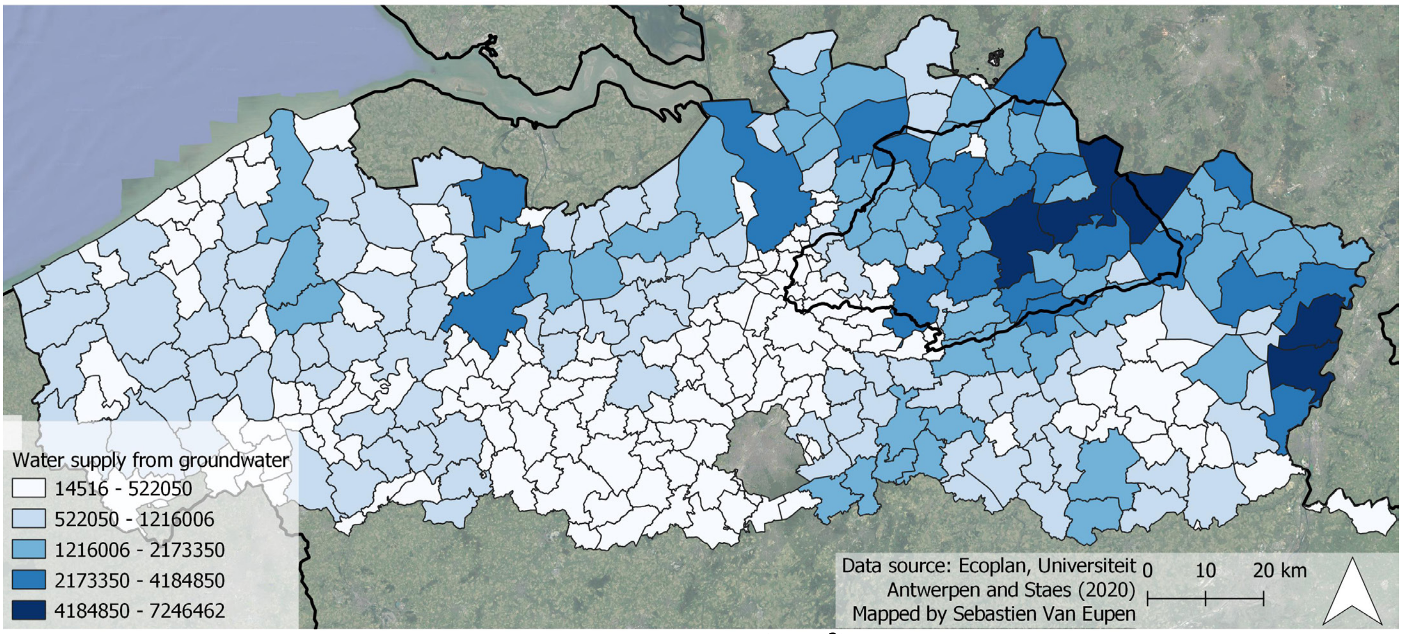
In the Nete basin, 70% of the wetlands are drained for agriculture (Verhoestraete & Staes, 2019). Consequently, valley groundwater levels and groundwater levels in elevated areas decreased. In addition, the elevated sandy dunes parallel to the valley systems were covered with pine trees resulting in lower rainwater infiltration rates. Groundwater loss due to drainage practices is twice the amount of water that is prevented from infiltrating the soil due to soil sealing or sewerage in the Nete basin. Therefore, the current focus on reducing soil sealing will not significantly impact future drought events.

Map 43 presents the total yearly groundwater supply per municipality in Flanders. It highlights the Campine region's function as a primary supplier of groundwater in Flanders. Additionally, map 44 highlights the Nete basin as a region with a very high groundwater extraction stress. Meaning that this area's extraction rate is a third of the potential maximum extraction. Note that groundwater reserves would be depleted if the actual extraction reaches the potential extraction.

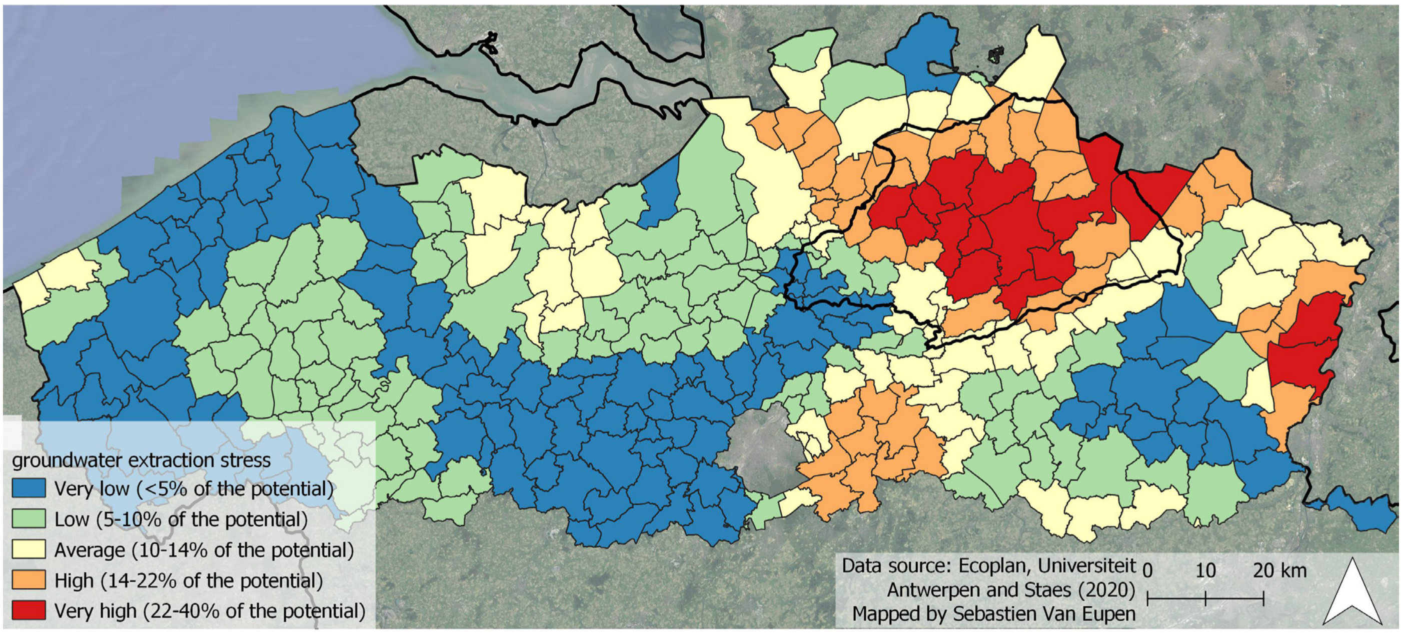
Therefore, significant annually recurring drought periods and resulting decreased groundwater levels could compromise the water supply in Flanders, as the Nete basin supplies a relatively large amount of groundwater and is subject to high levels of groundwater extraction stress.

In essence, the drought strategy cases considered for the Nete basin in this thesis attempt to enhance rainwater infiltration and retention. "Holding or storing more water does not require revolutionary knowledge or technology: it is not rocket science. However, it will certainly cost some money, although this is likely to be much less in the end than what the repair of material damage will otherwise cost us in the coming decades" (Didde, 2021).

Staes (2018) states that Flander is a typical example of a region with high costs due to the degradation of ecosystems. This thesis attempted to set out different cases along the Kleine Nete and explore drought strategies starting from nature-based solutions.



Map 43: Total yearly groundwater supply per municipality (in m³)



Map 44: groundwater extraction stress in Flanders (actual versus potential extraction)

Section three illustrated that there is a drought policy that could potentially improve Flanders' drought resilience. But, the actual impact on spatial planning practices remains to be seen. Especially the approach toward the agricultural stakeholder will be significant in implementing drought policies. Still, promising projects such as currently establishing Beek.Boer.Bodem, a collaboration between farmers and nature conservationists to develop methods to reduce climate change's impact on the Kleine Nete valley, proves to be promising.

Additionally, recent research by Staes et al. (2021) provides promising spatial drought planning tools. The University of Antwerp's research group, Ecosystem Services, developed a Water System Map, which models (very) shallow soil water. This map indicates areas for rainwater infiltration and retention and areas which would ideally be set up as permanent wet areas. This dataset is only available for a fee and is thus not considered in this thesis's scope. Furthermore, the same research group presents Ecoplan. Ecoplan develops tools and methods to facilitate "planning for ecosystems services" (***ECOPLAN Tools | Ecoplan | Universiteit Antwerpen***, n.d.). Different tools are (being) developed for different phases of the planning process: (problem) analysis, vision creation, plan development and eventually implementation. Additionally, these tools quantify ecosystem services for planning purposes. Unfortunately, during the development of this thesis, the toolbox was not available due to cybersecurity issues.

Section four was dedicated to answering the research question of which spatial drought strategies could be implemented, considering relevant stakeholder demands and areas hydrology, geomorphology and land use. Section four regarded that the primary approach to mitigate drought in the Nete basin is creating wetlands, heathlands on sandy dunes and agricultural parcels with woody hedges on elevated areas to facilitate rainwater infiltration and retention conditions. Foré et al. (2012) illustrated that landscape transformation, which would provide space for water, could consider the agricultural stakeholder and the region's cultural identity. Still, given the current climate change and, therefore, drought challenges, a business-as-usual scenario for agriculture would not be viable if drought policy is implemented to the extent that it would be effective. Currently, Flanders' drought policy still has a long road ahead to provide a sufficient planning basis which could have a meaningful impact. Therefore, spatial planners and researchers should thoroughly monitor the effect of the drought policy that is currently being developed. This thesis focused on pragmatic solutions for drought in the existing urban fabric. Increasing Flanders' drought resilience through nature-based solutions is a spatial challenge. To fully maximize and deliver these nature-based solutions at the scale and pace needed, it must be put at the heart of countries' national development and climate strategies. In that way, dealing with the defused urban fabric in Flanders stands at the centre of the resilience debate. Nature builds resilience through complexity. From this perspective, complex nature-based solutions should be developed throughout whole river basins for Flanders to be able to cope with future climate change uncertainties.

As a final remark, drought mitigation strategies potentially increase Flanders' resilience. But, drought mitigation strategies are not a way of bypassing climate change mitigation strategies. The proposed drought strategies are insufficient without a thorough decrease in global net anthropogenic GHG emissions toward carbon neutrality by 2050. Global climate change mitigation is one of Flanders' best drought mitigation strategies despite all measures. Therefore, discussing drought strategies should be embedded in a thorough, ambitious climate change mitigation transition for it to be effective. As with many extensive global problems, there a no silver bullets. Drought mitigation strategies are no exception.

APPENDIX

A. Legend of the Regional Zoning Plan of the Nete basin

Nete

- Nete_basin

planning destinations

- abdijgebied
- agrarische gebieden
- agrarische gebieden met ecologisch belang
- ambachtelijke bedrijven en kmo's
- bestaande autosnelwegen
- bestaande waterwegen
- bosgebieden
- bosgebieden met ecologisch belang
- bufferzones
- dienstverleningsgebieden
- gebieden hoofdzakelijk bestemd voor de vestiging van grootwinkelbedrijven
- gebieden voor dagrecreatie
- gebieden voor de vestiging van kerninstallaties
- gebieden voor gemeenschapsvoorzieningen en openbaar nut
- gebieden voor jeugdcamping
- gebieden voor verblijfrecreatie
- gemengde woon- en industriegebieden
- golfterrein
- groengebied met vissershutten
- groengebieden
- industriegebied met bijzondere bestemming (testen van autovoertuigen)
- industriegebieden
- landelijke gebieden
- landschappelijk waardevolle agrarische gebieden
- lokaal bedrijventerrein met openbaar karakter
- milieubelastende industrie
- milieubelastende industrie
- militaire gebieden
- museumcentrum (in natuurgebied)
- natuurgebied met bijzondere voorschriften voor de kleinijverheid
- natuurgebieden
- natuurgebieden met wetenschappelijke waarde of natuurreservaten
- parkgebieden
- pleisterplaats voor nomaden of woonwagenbewoners
- recreatiegebieden
- recreatieve parkgebieden
- regionaal bedrijventerrein met openbaar karakter
- restgebiedjes
- stortgebieden voor gepollueerde gronden (met zware metalen vervuilde grond)
- tijdelijk gebied voor gemeenschapsvoorzieningen (autokeuring)
- vliegveld / recreatie-gebied (gp Turnhout)
- woongebieden
- woongebieden met cultureel, historische en/of esthetische waarde
- woongebieden met landelijk karakter
- woongebieden met landelijk karakter en cultureel, historische en/of esthetische waarde
- woonpark
- woonuitbreidingsgebieden
- zone met cultuurhistorische waarde
- zone voor handelsvestigingen

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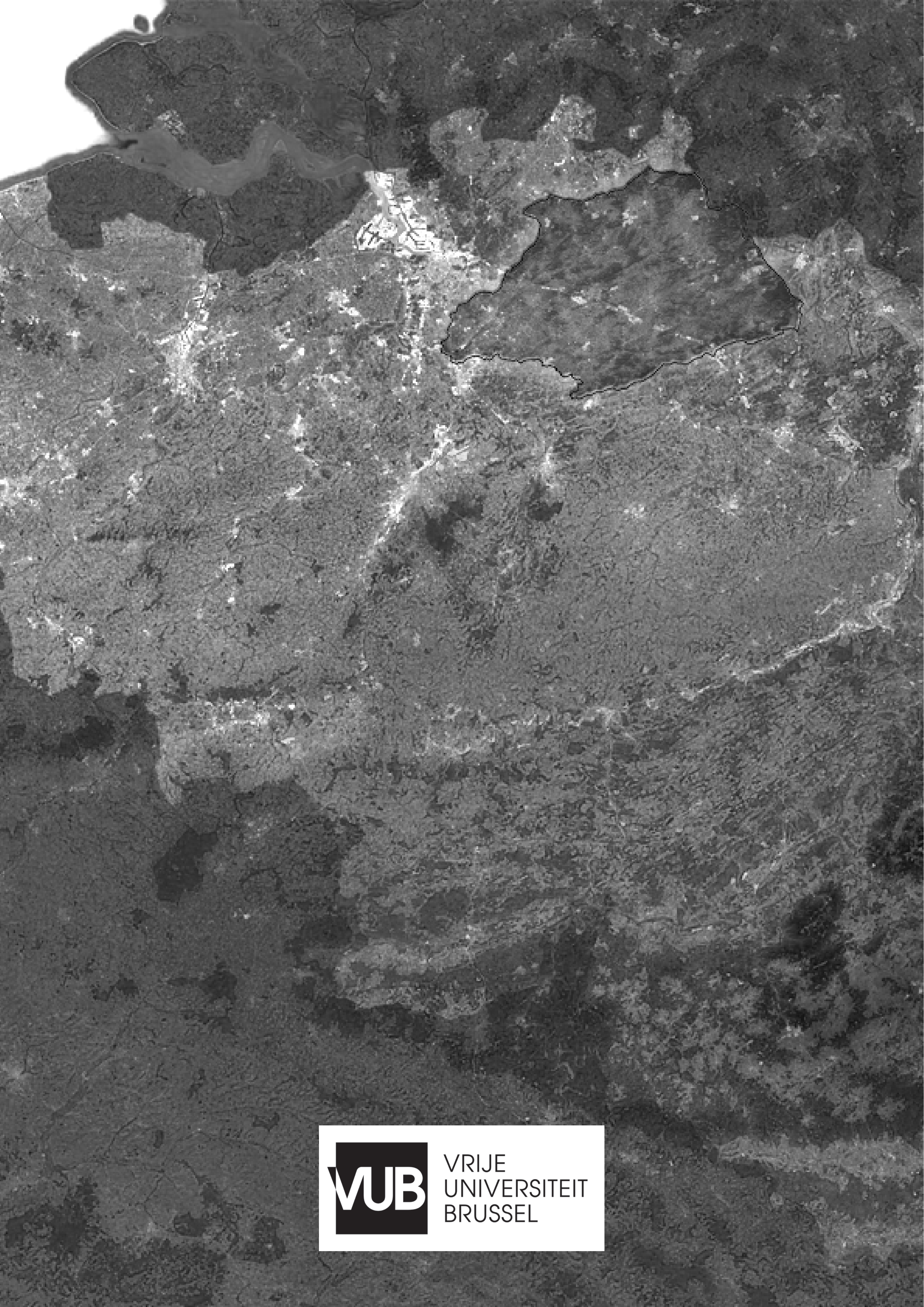

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