Optimizing the water allocation system in the Dutch region by adopting the WEAP model

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Abstract

Water scarcity has increased worldwide due to climate change, rapid population growth, socio-economic development, and environmental degradation leading to water resource crises. A critical challenge in combating droughts is optimizing water resources allocation to meet ecological, economic, and social needs in uncertain future climate change conditions.

In the Netherlands, the groundwater extraction leads to drying neighboring nature reserves due to a declining groundwater table and groundwater quality deterioration affecting groundwater resources sustainability. Extensive areas have been drained to build houses, and groundwater withdrawals for drinking water, agriculture, and industry usage have also increased. That causes local shortages of groundwater. As a solution to water resources management issues, researchers and scholars have emphasized applying several simulation or optimization modeling techniques to develop decision support systems for improved water resources management.

This research used a Water Evaluation and Planning (WEAP) model to obtain insights for water resources management strategies for the municipality of Laarbeek, the Netherlands. The groundwater resource pressure was alleviated by new connections between water users and water supplies in the catchment. The research aims to minimize groundwater use in the study area. In WEAP, a current situation in the watershed and nine developed scenarios in water demand, quality, and availability in River Aa was simulated.

To sum up, the study area's relevant water users are identified as follows; drinking water company (Brabant Water), industry, and farmers. Industrial water demand was accounted for only Bavaria Brewery. The reported volume of groundwater extracted in 2019 was 2,5 million m^3. Municipal water demand in Laarbeek was supplied by the drinking water company, Brabant Water. Municipal yearly water consumption was equal to nearly 1 million m^3/y. Agricultural water demand corresponds to irrigation use in Laarbeek. It was simulated based on the groundwater that farmers extracted in 2019 in the study area and how much of the treated effluent was delivered from WWTP Bavaria Brewery they had used. The total annual water demand was 1,7 million m^3.

It is crucial that purified effluent from wastewater treatment plants is reused and remains in the area. The scenario analysis showed that the reuse of wastewater for irrigation is feasible in the study region. An advantage of water quality modeling is that it is possible to simulate the pollutant loads added as a stream discharge from a wastewater treatment plant. Therefore, it was shown how wastewater from a wastewater treatment plant affects the River Aa's water quality.

Furthermore, the reuse of wastewater affects the natural availability and quality of river water. As in the Netherlands, the flow of a river depends on the effluent that makes it flow, especially during the summer months. Therefore, if the wastewater is reused and not discharged into the river, the stream's flow decreases. Additionally, the quality of the River Aa is improved by reusing wastewater. Since the wastewater treatment plant does not remove 100% of the pollutants, the pollutants are discharged into the river. If wastewater is reused, fewer pollutants are released—consequently, the more treated wastewater reused, the better the streams' quality.

Keywords

Water Evaluation and Planning (WEAP) model, water allocation, reuse wastewater, water quality

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1. Introduction

1.1. Water scarcity impacts

A great deal of awareness on water scarcity has been raised globally due to its effect on the social and economic sectors and the well-being of ecological systems (Bijl et al., 2018). A critical challenge in combating droughts is optimizing water resources allocation to meet ecological, economic, and social needs in uncertain future climate change conditions. The rapid increase in water demand due to population growth, socio-economic development, and environmental degradation has led to natural water resource crises worldwide. Causing an imbalance between supply and demand exacerbates the pressure on water resources, putting constraints on water supply, and creating conflicts between water sectors (Wang et al., 2003).

Water scarcity is considered as one of the main threats to the sustainable development and management of water resources, affecting many social and environmental sectors in various communities and parts of the world up to recent years (Liu & Savenije, 2008; Syme, 2014; Syme & Nancarrow, 1997; UN-Water, 2007). As the limits of water resources are better understood, it is essential to develop effective water allocation and management strategies that optimize economic and social well-being and equitably, without compromising the ecosystem's sustainability (OECD, 2010; Speed et al., 2013; Wang et al., 2003).

1.2. Wastewater reuse

The reuse of the effluent water from the Wastewater Treatment Plant (WWTP) can be a solution for water shortages. Numerous sectors could use reclaimed water before being transported to the atmosphere and the sea (Alcalde Sanza & Gawlik, 2014; Kirhensteine et al., 2016).

As an alternative water source, water reuse can provide significant economic, social, and environmental benefits. It can enhance natural and artificial flow in streams and ponds, thus helping to reach quantitative targets for surface water bodies. Moreover, reusing effluent to recharge aquifers can prevent deterioration of groundwater resources. Wastewater reuse for irrigation would encourage more productive agriculture. Also, it could provide an increase in economic activities because water reuse would lead to social benefits such as employment. For instance, for tourism industries, water reuse would indirectly encourage tourism development by allowing the development of water-related activities such as golf courses, parks, or hotels (Alcalde Sanza & Gawlik, 2014; Kirhensteine et al., 2016; The European Commission, 2018).

Nevertheless, reclaimed effluent water can contain a wide range of risks, including microbiological, chemical, physical, and radiological agents that can pose a risk to human health and environmental well-being (Kirhensteine et al., 2016). The most important health and environmental risks associated with the use of recycled water are pathogen microorganisms and chemical contaminants. Many pathogens in reused wastewater are of intestinal origin. Chemical hazards such as nitrogen, phosphorous, chloride, and sodium must also be taken into account, especially when recycled water can be used directly (Alcalde Sanza & Gawlik, 2014; Kirhensteine et al., 2016; The European Commission, 2018).

1.3. Water management in the Netherlands

The Netherlands is a small country in Western Europe, including inland water of 41.540 km^2 and a population of 17,4 million people (European Union, 2020; StatLine, 2020). The country is located in the delta of the three main northwest European rivers: the Scheldt, the Rhine, and the Meuse. A large region of the country is subjected to sea and river floods, and waterlogging (Huisman, 2004). The average annual precipitation is around 800 mm. The mean yearly potential evapotranspiration is equal to 550 mm. The maximum potential precipitation deficit, occurring in April to September, accumulates on average between 100 – 150 mm. In exceptionally dry years, the maximum summer deficit may be as large as 300 mm (OECD Studies on Water, 2014; Vries, 2007).

Water security is of fundamental importance in the Netherlands. Furthermore, industrial and urban water pollution has decreased considerably since 1970 in the country. However, there is still much historical pollution in the form of contaminated sediment. Dutch agriculture is very intensive and uses around two-thirds of all land (Mostert, 2006). Therefore, the main problem substances in the groundwater and surface water bodies are nitrates and phosphates from agriculture (RIVM, 2016).

The regions in the southwest, east, and northeast of the Netherlands, regions with sandy soil, may experience water shortages during dry periods. The Netherlands extensively uses groundwater extractions for anthropogenic purposes such as drinking water production, irrigation water for agriculture, and process water for industry (Attema et al., 2014).

In the last decade, the groundwater table in the Netherlands has dropped significantly; according to future climate predictions, this trend is bound to continue (Attema et al., 2014; Runhaar et al., 1996). The decline of the groundwater table causes a decrease in the soil moisture content, which may cause a reduction in crop yield (Kundzewicz & Döll, 2009). Agricultural yields considerably depend on the amount of moisture in the root zone. In dry months, there is frequently a shortage of soil moisture, which decreases agricultural yields. This refers to an annual loss of around 50 million euros for the sandy soil regions. If water management does not change, as the climate becomes more and more irregular, the water shortage will worsen. Damage in the agricultural sector due to drought can rise up to 140 million euros per year (Klijn et al., 2011).

Adaptation measures to minimize the risk of drought are of high economic importance. During dry months with low soil moisture, yields are highly reliant on irrigation. The actual evapotranspiration of the plants and the soil evaporation is then higher than the amount of precipitation. As soon as the water supply in the root zone of the soil decreases and capillary redelivery of water from the groundwater cannot keep up with this decrease, moisture shortages occur for crops. This makes the transpiration of the plants; thus, the crop grows less than its potential. At, or before the point of moisture shortage, irrigation water supplies are needed to prevent crop damage. Extended and extremely dry periods are expected to occur in the future. This increases the risk of moisture shortages if there is no irrigation, or insufficient irrigation water, that can be supplied. In large parts of the south and east of the Netherlands, supply from the primary water system (large rivers and canals) is not directly feasible, and irrigation depends on groundwater or local surface water. These regions have a majority of sandy soils. By extracting local groundwater, declining groundwater levels can shift the damage to surrounding agricultural plots or affect natural functions. In dry periods, the extraction of local surface water is also not feasible because sufficient water (and current) must remain available for organisms living in surface water (Bartholomeus et al., 2017).

Water scarcity can be reduced by avoiding draining unused sewage but using it to combat drought (Bartholomeus et al., 2018). Depending on the weather conditions, about 17% to 35% of the Dutch surface water relies on the WWTP effluent in the dry months. These numbers do not include the contribution of industrial discharges (Bartholomeus et al., 2017; OECD Studies on Water, 2014).

1.4. The WEAP tool to approach water resource management

As a solution to water resources management issues, researchers and scholars have emphasized applying several simulation or optimization modeling techniques to develop decision support systems for improved water resources management. Rees & Ellner (2006) delivered practical software to help make a water balance between natural water resources and water demands (Rees & Ellner, 2006). Giupponi (2007) developed a Decision Support System (DSS) for integrated water resource management (IWRM) to help the decision-makers in water allocation between different sectors

(Giupponi, 2007). Letcher et al. (2006) proposed a generalized conceptual framework that considered water allocation, agricultural production, and water use decisions and their interaction with the river system (Letcher et al., 2006).

The WEAP, the Water Evaluation and Planning model, is a typical application that links supply and demand site requirements. It allows for analyzing and evaluating changes in supply and demand structures by simulating user-defined scenarios where the physical and social variables at play are changed. Scenario analysis is used, for instance, to discover potential shortages and the effects of different management strategies (Sieber & Purkey, 2015). WEAP describes a new generation of water planning software that uses the powerful capability of today's personal computers to give water professionals everywhere access to suitable tools. The WEAP model was developed by the Stockholm Environmental Institute (SEI). The WEAP model can be applied to municipal and agricultural systems and can cover an extensive range of functions, including sector demand analysis, water rights, water conservation, and allocation priorities, reservoir operation, streamflow simulation, ecosystem requirements and cost-benefit analysis of the project (Sieber, 2006). The model consists of two fundamental functions (Sieber & Purkey, 2015):

- Simulation of natural hydrological processes to assess the availability of water in the catchment;
- Simulate anthropogenic activities imposed on the natural system to influence water resources and allocate them to evaluate the impact of human water use.

1.5. Problem statement

In the Netherlands, surface water resources are typically managed and relatively well understood, while groundwater resources are often hidden and more challenging to conceptualize. Replenishment rates of groundwater decreased in many parts of the country (Everett & Zektser, 2004). Besides, the remaining groundwater also shows a decline in quality. Therefore, it has become more common that the deterioration in groundwater quality and quantity cannot support all agricultural, industrial, and urban demands and ecosystem functioning (Jakeman et al., 2016; Jiggins et al., 2007).

When the groundwater withdrawal exceeds the total recharge, a stable end situation cannot be achieved as long as the pumping is not reduced. Hence, after a period of continuous extraction of groundwater that is larger than the aquifer's natural flow, the storages (reserves) are being lowered. The physical limit is the depletion of storage in some regions of the aquifer, which means that pumping cannot be performed due to insufficient water quantity. Nevertheless, other limits depend on the degradation of the extracted groundwater's quality, such as increased salinity or unwanted chemical changes (Everett & Zektser, 2004).

It is essential to reduce groundwater extraction to a minimum if this is possible. Moreover, surface water on the earth renews as part of the hydrologic cycle during an average period ranging from approximately 16 days (rivers) to 17 years (lakes and reservoirs); however, the average renewal time for groundwater is approximately 1,400 years, with millions of years for some deep fossil groundwater (Mays, 2013). Therefore, it is crucial to allocate water resources in the way that groundwater extraction will be minimized.

In the Netherlands, farmers extract high-quality shallow groundwater for low-value use, such as irrigation. Overextraction can lead to neighboring nature reserves drying due to a declining groundwater table and groundwater quality deterioration by industrial pollution, nitrates, and phosphates, pesticides, and acid rain (Hellegers et al., 2000). Extensive areas have been drained to build houses, and groundwater withdrawals for drinking water and industry usage, causing local shortages of groundwater (Hellegers et al., 2000). Hence, the WEAP model can provide insights for efficient water resources management strategies.

1.6. Research objective

This research aims to provide elements for water allocation strategy in terms of water quantity and quality in the municipality of Laarbeek, the Netherlands, in order to minimize the consumption of groundwater in the region by making new connections between water users and supplies. The study is carried out using the WEAP tool to model various scenarios regarding water allocation.

1.7. Research question

RQ: How can the pressure on the groundwater resources be alleviated by making new connections between water users and water supplies?

1.7.1. Sub-questions

- SQ1: What are the environmental flow requirements in the selected catchment?
- SQ2: What are the relevant water supplies and water users, and their needs in the study area?
- SQ3: How does water quality in streams change in different water allocation scenarios?
- SQ4: How does effluent water reuse affect natural water availability in streams?

1.8. Hypothesis

By making new connections between water supplies and water users, effluent reuse can be increased resulting in less groundwater resource use while minimizing the impact on water quality.

2. Literature review

This chapter covers six sections to make this research more feasible for the region in which it is conducted. The information on the water allocation in the Netherlands provides an overview of water priorities supply according to Dutch law, which was used further for developing future scenarios. The description of future climate change in Laarbeek, particularly temperature and precipitation patterns, indicates the basin's future situation. Furthermore, an overview of the case study that was carried out previously describes what has been done so far with the reuse of wastewater in the study area. Besides, the reuse of the current wastewater situation in Europe is very valuable for this research. Because when developing scenarios, it should be noted that they are realistic and can be applied to the municipality of Laareek. The Dutch freshwater quality is essential to be addressed since it was modeled in the WEAP tool. Finally, the environmental flow requirements are explained to understand the theory behind it better and define it.

2.1. Water allocation in the Netherlands

In the Netherlands, the distribution and licensing of extraction rights are primarily governed by the priority list, and licensing rules set out in the Water Act (sections 2.9 and 6.6, respectively) (van Rijswick, 2015). The Water Act includes a list of priorities for the allocation of freshwater in the event of a drought. Section 2.9 (1) specifies that the social and ecological priorities that will determine the distribution of the available surface water in the event or threat of a water shortage will be fixed by administrative decree as provided for in the Water Decree. Under subsection (2), further rules can be brought in by administrative or provincial order regarding the priority list and may also be applied to groundwater distribution. Section 2.1 of the Water Decree details the list of priorities; those of the last two categories can be specified at the regional or provincial level (van Rijswick, 2015).The list of priorities is as follows (van Rijswick, 2015):

1. *Guaranteeing flood protection and prevention irreversible damage;*
2. *Public utilities, with drinking water having the highest priority as far as delivery reliability is concerned, followed by the power supply, likewise as far as delivery reliability is concerned;*
3. *Small-scale high-grade use, prioritized as follows:*

   a. *temporary sprinkler irrigation of capital-intensive crops;*
   b. *processing industrial process water;*
   c. *the quality of water in urban areas;*
4. *Other needs, with the following order of priority: shipping, agriculture, natural environment, industry, water recreation, inland fishing, drinking water, and energy);*
5. *'Other' interests.*

2.2. Climate change in the municipality of Laarbeek

The climate is changing. Annual mean temperature rises, and heatwaves become more common than usual, it gets drier, and at the same time, the precipitation events are more extreme. The consequences of this are already noticeable through environmental, economic, and public health damage. The Royal Dutch Metrological Institute (KNMI) translated the IPCC Report 2013 to determine what the climate change effect will be for the Netherlands. The KNMI '14 climate scenarios for the Netherlands are based on perceived changes in the climate, recent calculations made with worldwide climate models for the IPCC, and calculations with the climate model for Europe by the KNMI (Attema et al., 2014).

Additionally, in 2014, the Delta Decision on Spatial Adaptation was adopted, in which municipalities and other authorities were given the goal of designing the Netherlands in 2050 to be climate-proof and water-robust. The following results of climate change describe the change in temperature and precipitation pattern of the municipality of Laarbeek (Veltmaat, 2020). KNMI scenarios (2014) show that the expected amounts of annual rainfall will increase by about 50 mm in 2050. The WH250 scenario is shown, which has the highest precipitation of the four KNMI'14 scenarios. The WH scenario takes into account a temperature rises of 2 ° C worldwide around 2050 and a substantial change in airflow. The increase in total precipitation is small. However, the intensity and extremity of the showers are increasing. According to the KNMI, the intensity of heavy rain showers will increase by 12 to 25% until 2050. This increase is related to the temperature increases because warmer air can contain more water vapor. The same or higher amount of precipitation falls in a shorter period (especially in summer) or long-term heavy rainfall (especially in autumn and winter). In particular, this increases the risk of flooding. Table 1 shows that the chance that extreme showers occur will increase sharply in the future (Veltmaat, 2020).

TABLE 1: ANNUAL RAINFALL AND POTENTIAL RAINFALL DEFICIT IN LAARBEEK (VELTMAAT, 2020).

	Current	WH2050
Annual rainfall	800-850 mm	850-900 mm
Potential rainfall deficit	120-150 mm	210-240 mm

Dry periods generally occur during the summer, which is also the growing season (April 1 to September 30) for most crops. July 2018 had a drought record: an average of 11 mm of rainfall. Usually, that month is 78 mm. From the model results (2014) of KNMI climate scenario WH2050, it can be seen that the potential annual average rainfall deficit in the current climate is 120-150 mm and that this can increase to 210-240 mm in 2050. An increase in the precipitation shortage can lead to a further decrease in water availability in groundwater and surface water and an increase in water demand for water level management and irrigation. The water quality can also come under pressure, for example, due to a reduced flow of surface water (Veltmaat, 2020).

2.3. Boer Bier Water case study

The reuse of purified process wastewater from Bavaria Brewery in Lieshout for agriculture water supply is a part of the "Boer Bier Water" initiative (Swinkels Family Brewers, 2020). Bavaria Brewery extracts 2,5 million m^3 of groundwater annually and discharges 1,5 million m^3 into the River Goorloop, accelerating its departure from the area. At the same time, local farmers make extensive use of groundwater to irrigate their crops. The irrigation requirements from groundwater are reduced by reusing the reclaimed water from Bavaria Brewery for the regional agricultural water supply. Therefore, water is returned to the regional groundwater system. It reduces desiccation and makes the water system more robust for periods of drought (van der Heide & Polman, 2016).

The common interest of all the relevant stakeholders is conserving the groundwater, sustainable use of soils, and creating an image towards sustainability. So far, farmers have received financial compensation from the Bavaria Brewery in case of drought. The ultimate goal of this initiative is to maintain a sufficient quality and quantity of groundwater in the region (Bartholomeus et al., 2017).

In 2016, Bavaria Brewery started using cement mortar in WWTP. The residual water is transported to a nearby grassland, which has led to increased irrigation by sub-irrigation with drains (Bartholomeus et al., 2017). In the first relatively wet year (2016), approximately 28,000 m^3 of treated wastewater was supplied. The cost of building a level control drainage system is 2,500 EUR / ha. Assuming a depreciation period of 25 years, this equals 100 euros per year (Bartholomeus et al., 2017).

Besides, by building the mortar, it is possible to put residual water to the nearby Wilhelminakanaal. Currently, it is impossible to use the water from the reservoirs of this canal for irrigation. However, the brewery supply will allow the reservoir to function as temporary water storage and means of transport. Hence, the treated process water from the brewery can be reused in many other parcels (Bartholomeus et al., 2017). An estimated 0,25 to 0,5 million m^3 of brewery's wastewater is reused to supply local agricultural water. Therefore, farmers do not need to extract as much water from groundwater, which limits further desiccation. Farmers also save on energy costs for extracting groundwater for irrigation. (Bartholomeus et al., 2017).

Gradually, more residual water from Bavaria Brewery can be reused in the future. In this regard, the role of the canal as a buffer and a means of transport is crucial. Therefore, all the brewery's residual water can be used in the spring and during the growing season. For instance, groundwater extraction for a production process in Bavaria Brewery and the supply of treated wastewater for the local agricultural water supply is increasingly sustainable (Bartholomeus et al., 2017).

2.4. Reuse of treated wastewater in Europe

Water reuse is described as the use of water generated from wastewater, which accomplishes, after treatment as required, a consistent quality (taking account of the health and environment risks and local and EU legislation) for its intended use(The European Commission, 2016).

The reuse of water is primarily a local solution to a local problem. However, its contribution to the fight against water scarcity must be analyzed at the national, regional, or watershed levels. In summary, the potential environmental benefits of a water reuse program include (Alcalde Sanza & Gawlik, 2014):

- Water reuse preserves freshwater resources, especially in areas affected by water scarcity, allowing adaptation to future changes in long-term demand and availability, such as climate change;
- Water reuse reduces unexpected risk to health and the environment;
- Water reuse can reduce greenhouse gas emissions due to using less energy to properly treat and manage wastewater compared to importing water, pumping groundwater to deep water, and water desalination.

The need for irrigation is increasing in the several EU Member States, including the Netherlands. Thus, alternative sources such as treated wastewater represent an economic opportunity. Moreover, the supply of the purified wastewater is reliable even during the droughts period. Consequently, it is feasible to reduce the risk of loss of crop production and guarantee individual farms' access to water resources. Besides, in the water scare areas, the reclaimed water could be used in greenhouses. When reused water provides nutrients, farmers can also benefit financially from lower fertilizer costs. This water is likely to contain contaminants; hence risk assessment is necessary to be conducted (Alcalde Sanza & Gawlik, 2014; The European Commission, 2016).

Industrial water users are also substantial users of wastewater reuse for various processes, such as process water, cooling, boiler feed, and plant cleaning, as well as for toilets and other sanitary applications. The primary water users and wastewater producers are the chemical sector, the pulp and paper industry, the beverage sector, the textile sector, and the aggregate (Alcalde Sanza & Gawlik, 2014; The European Commission, 2016).

2.5. Freshwater quality in the Netherlands

According to Dutch standards, eutrophication is represented not only by the average content of chlorophyll-a in summer but also by the average concentration of total nitrogen and total phosphorus in summer months (April to October). Consequently, the summer average is used to determine the degree of eutrophication of various water bodies (Rombout et al., 2007). The nitrogen concentration is an indicator of the number of nutrients present and the algae biomass (RIVM, 2016).

As reported by the EU guidelines (CE/DGXI, 2011), nitrate-nitrogen is considered the essential variable for presenting the impact of agriculture on the water quality in the area. In water vulnerable to eutrophication, some nitrates disappear as the nitrates are absorbed by the algae during the summer, giving a distorted picture of the summer monitoring results. The higher the degree of eutrophication of the water reservoir, the more significant the reduction in nitrate concentration in summer. Another critical factor in the Netherlands' situation is that in summer, upward infiltration and water ingress from other areas into the polders can affect the measured water quality. Therefore, the winter average (October to March) gives a more representative image than the summer or annual average (RIVM, 2016).

2.5.1. Nitrogen

Nitrogen is an essential nutrient for plants and animals. However, too much nitrogen in waterways can lead to eutrophication, and the algae take up the oxygen. Sources of nitrogen include WWTPs, runoff from fertilized lawns and farmland, septic tank failures, runoff from storage areas and manure, and industrial discharges containing corrosion inhibitors (USGS, 2004).

The summer average total nitrogen concentrations have declined since 1992 in the Netherlands, as shown in Figure 1. The improvement in water quality is the result of measures taken by the Netherlands under the European Nitrates Directive. An example is the obligation to use less manure. In the years 2012-2014, on most farms, nitrate concentrations in farm water near clay and peat were below the European standard (50 mg/l) (Fraters et al., 2016). The Total Nitrogen concentrations for both Water Framework Directive (WFD), regional and national waters, are comparable (2,9 mg/l) while those of the agriculture-specific waters are higher (3,5 mg/l) (RIVM, 2016).

The volume of precipitation has a significant influence on the nitrogen concentrations measured in surface water. The total concentration of nitrogen is usually higher in wet years than in dry years. It is partly due to the higher proportion of relatively nutrient-rich shallow flow pathways contributing to surface water in wet circumstances (Rozemeijer et al., 2010; Rozemeijer & Broers, 2007). In dry conditions, the opposite applies: the relatively high proportion of deeper, cleaner groundwater contributes to surface water. Climate conditions could explain the low average concentrations in 1990 and 1991: these were two relatively dry years. The high total nitrogen concentration for 1998 is an extremely unfavorable year for surface water quality as a very wet year (Klein & Rozemeijer, 2015).

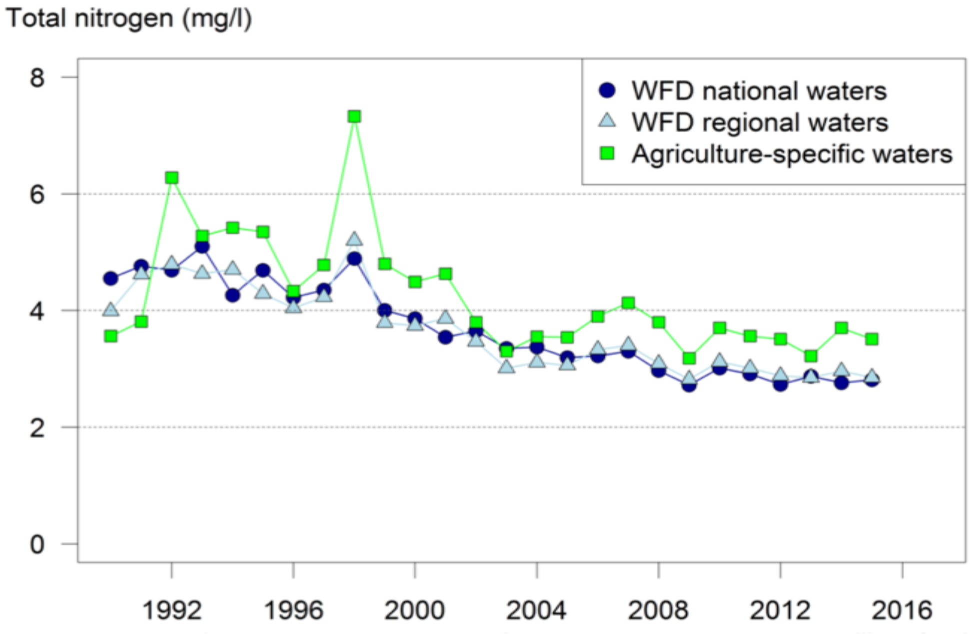

FIGURE 1: TOTAL NITROGEN CONCENTRATION (SUMMER AVERAGES AS N IN MG/L) IN FRESH WATERS IN PERIOD 1990-2015; WFD- EUROPEAN WATER FRAMEWORK DIRECTIVE (RIVM, 2016).

2.5.2. Phosphorus

Phosphorus is primarily an essential nutrient for all plant and animal life, often as phosphate in inorganic fertilizers. Simultaneously, phosphate and organophosphates are extensively used in applications such as detergents, flame retardants, plasticizers, pesticides, and scale inhibitors in water heaters or boilers (USGS, 2011).

In the Netherlands, since the beginning of the 1990s, the summer average total phosphorous concentration has been gradually decreasing in the WFD national waters, as can be seen in Figure 2. After 2010 there was a sharp drop to 0,12 mg /l of total phosphorous. In the case of the WFD regional waters, the phosphorus concentration dropped drastically until 2005, but in the following years, it stabilized at around 0,26 mg /l. The total phosphorous concentration in agriculture-specific waters has been unstable. In 1998, the phosphorous concentration reached the highest since it was a very wet year. In 2015, it was established that the total phosphorus concentration is approximately 0,4 mg/l in agriculture-specific waters (RIVM, 2016).

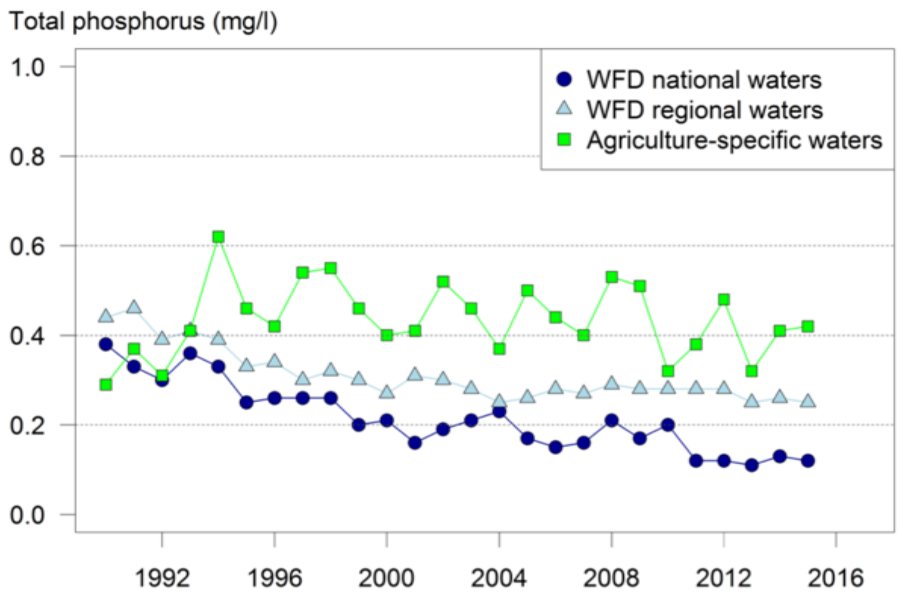

FIGURE 2: TOTAL PHOSPHOROUS CONCENTRATION (SUMMER AVERAGES AS P IN MG/L) IN FRESH WATERS IN THE PERIOD 1990-2015; WFD- EUROPEAN WATER FRAMEWORK DIRECTIVE (RIVM, 2016).

2.6. Environmental flow requirements

As stated in the Brisbane Declaration (2007), *environmental flows describe the quantity, quality and timing of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems* (IRF - International River Foundation, 2007).

As the demand for water for food production and other human needs increases, quantifying environmental flow requirements (EFRs) is essential to assess the amount of water required to maintain freshwater ecosystems. The EFFs result from quantifying the water needed to maintain a fluvial ecosystem (Pastor et al., 2014).

Hydrological methods have been developed for large-scale planning and use only readily available discharge data (Shaeri Karimi et al., 2012). Hydrological methods are commonly based on minimum annual flow thresholds, for instance, 7Q10, the lowest flow during seven consecutive days every ten years or Q90 where the streamflow exceeds 90% of the registration period (NGPRP, 1974).

Critical environmental flow as the 90th percentile over groundwater discharge records focuses on the dependence of ecosystem functions and services on streamflow under low flow conditions. The proportion of groundwater discharge in the streams is the highest. The natural and human-made results can be compared to distinguish environmental flow restrictions to provide an overview of the minimum flow in a stream (Pastor et al., 2014).

3. Materials and methods

3.1. Study area

Laarbeek, the municipality in the province of Noord-Brabant located in the south of the Netherlands, covers an area of 56.17 km^2 with a total land area of 55.37 km^2 and inland water of 0,80 km^2. The map is shown in Figure 3. The study area has the following coordinates 51°32’N 5°38’E. The research area is in a River Meuse Basin. The elevation is 14 m. The Netherlands' climate is described as a mild maritime climate influenced by the North Sea and the Atlantic Ocean. Thus, it is cloudy, cold, and humid for a more significant period (CBS, 2011; Vries, 2007). The mean annual temperature is 11,5 degrees Celsius (KNMI, 2020a). The number of summer days with a temperature higher than 25 degrees Celsius is 30-40, and the number of tropical days with a temperature higher than 30 degrees Celsius is 6-9 days. Annual average precipitation is 800-850 mm (KNMI, 2020b; Veltmaat, 2020), and multiyear evaporation is approximately 5,69 kg/km^2. Dry periods generally occur during the summer, which is also the growing season from April 1 to September 30 for most crops (Veltmaat, 2020).The average monthly precipitation and air temperature data for 2019 can be found in Table 2. These data inputs were obtained from the Royal Netherlands Meteorological Institute (KNMI). The data was derived from the nearest meteorological station, which is located in Eindhoven. The most common wind direction in the Netherlands is southwest. It is the average highest wind velocity on the Dutch Meuse. This correlates to 8,0-10,7 m/s (Vries, 2007).

TABLE 2: AVERAGE MONTHLY PRECIPITATION AND TEMPERATURE IN STATION EINDHOVEN IN (KNMI, 2020b, 2020a)

Climate Variable	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Precipitation (mm)	65,5	45,9	88,3	20,2	34,4	81,1	29,3	41,3	50,9	93	72,7	84,9
Average Air Temperature (°C)	3	6,3	8,2	11,3	12,1	19,1	19,3	19,1	14,9	12,1	6,4	5,8

There are four major urban areas in Laarbeek, Aarle-Rixtel, Beek en Donk, Lieshout, and Mariahout. The agricultural area covers 3934 ha, and the forest with the open natural area is 571 ha. The agricultural land in 52% contains grassland and 48% of the arable land where mainly the maize (52%), potatoes (14%), and barely (1,4%) are cultivated (CBS, 2011; Pouwels, 2017). The geographical and geohydrological situations show that the area consists of a cover sand landscape, with a weak relief. The top formation is the Nuenen group, a heterogenic group with layers of sand, loam, and peat (Jalink et al., 2000). The Goorloop River, Aa River, the Wilhelminakanaal, and the Zuid-Willemsvaart canal are the surface water bodies in the surrounding area (CBS, 2011). There were 22,333 people living in Laarbeek catchment, according to CBS Statistics Netherlands data from January 2019 (CBS, 2020). The people depend on the drinking water supplied by the Brabant Water drinking water company.

The research area is part of a regional case for local groundwater and surface water resources in the municipality of Laarbeek. The case consists of the Bavaria Brewery, local farmers and the regional farmers Union (ZLTO), the water authority (Aa en Maas), the drinking water company (Brabant Water), the municipality, the province of Noord-Brabant, and the Ministry of Infrastructure and the Environment (Rijkswatrersaat) (van der Heide & Polman, 2016). Therefore, the location was chosen because it is a particularly interesting area where several stakeholders are presented, and some case studies were carried out (Jalink et al., 2000). The Bavaria Brewery uses purified industrial wastewater with farmers and water managers to reduce water scarcity in agriculture; thus, contributing to an economically healthy agricultural sector (van der Heide & Polman, 2016).

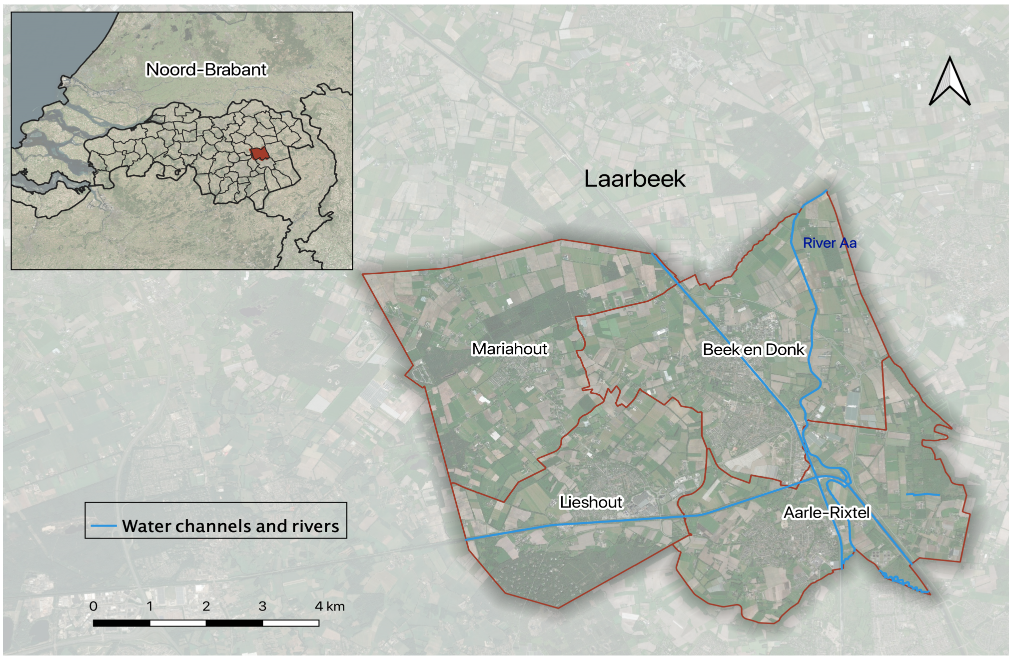

FIGURE 3: MAP OF A STUDY AREA.

3.2. Environmental flow requirements calculations

The hydrological method was applied in this research to calculate the EFRs in River Aa since only discharge data were available. Hydrological methods applied statistical procedures, percentiles, to the historical series of natural flows. The River Aa streamflow upstream data was collected from the water authority, Aa en Maas and can be seen in Appendix I.

Environmental flow calculations were made in Microsoft Excel with the use of the Flow Duration Curve (FDC). FDC is a cumulative frequency curve expressing the percentage of time during which the average discharge equals or exceeds a particular value at a given point (Mitra & Ajai, 2018). The FDC represented the daily values of discharge at River Aa upstream. The discharge data were ranked in descending order. Consequently, the Q90 index (daily flows exceeding 90% of the time, respectively) was used.

3.3. WEAP Model description

The basic WEAP algorithm is a spatially decisive water balance calculated monthly by balancing water supply and demand at each node and link in the system. Nodes represent points of supply or demand, and links connect them. This structure of nodes and connections enables aggregation and disaggregation of water balance components, if necessary, depending on the research question or available input data, and is applicable at all scales. It runs in the monthly water balance equation shown below (Sieber & Purkey, 2015; Yang et al., 2018):

EQUATION 1: WATER BALANCE EQUATION

$$\sum_{i=0}^{n} Q_{inflow,i} = \sum_{i=0}^{n} Q_{outflow,i} + Q_{consumption}$$

Where Q_{inflow} is the sum of all inflows at a node and all connected inflow links with the unit amount of water per time; $Q_{outflow}$ is a sum of outflow at a node and all connected outflow links; $Q_{consumption}$ is water consumed at a node and all connected links.

The elements that include the water demand system and their spatial relationships are characterized for the basin under consideration to simulate water allocation. The system expresses in terms of different water sources such as groundwater, surface water, WWTPs, reservoirs, and various water demands. The data structure and detail level can be customized to meet the specific analysis's needs and the data's potential limitations. The graphical interface facilitates visualization of the system's physical features and their layout within the catchment (Höllermann et al., 2010; Sieber & Purkey, 2015).

The WEAP model performs a mass balance of a flow sequentially in a river system, taking into account withdrawals and inflow. The river is divided into reaches in order to simulate the system. The reach boundaries are established by points in the river where a change is a flow due to confluence with a tributary, return flow, abstraction, or a flow gauging formation (Sieber & Purkey, 2015; Yang et al., 2018).

In general, the system configuration uses the WEAP model to simulate the recent "baseline" called Current Account, year for which water availability and demand can be determined. Consequently, the model is used to simulate alternative scenarios to assess the impact of various development and management options. The model optimizes water use in the basin using an iterative Linear Programming algorithm that aims to maximize water supply where there is demand, based on a set of user-defined priorities. All on-demand parts are assigned a priority from 1 to 99, with 1 being the highest priority and 99 being the lowest. When the amount of water is limited, the algorithm is formulated to gradually limit water allocation to the points of need that have the lowest priority (Arranz & Mccartney, 2007; Sieber & Purkey, 2015).

The water quality modeling in WEAP incorporates descriptive models of point source pollutant loadings that simulate wastewater's impact on receiving waters from demand sites and WWTPs. Water quality parameters that can be reconsidered in WEAP include dissolved oxygen (DO) and biological oxygen demand (BOD) from point sources, and instream water temperature, and conservative substances, constituents that decay according to an exponential decay function (Sieber & Purkey, 2015).

3.4. WEAP model setup for municipality of Laarbeek

Most of the data was available for the study area in 2019. Therefore, it was a baseline scenario (Current Account) in the WEAP model. The Setup module of WEAP is where the water resource system's supply and demand features are defined, and the system is configured. The elements of a WEAP schematic can be seen in Figure 4.

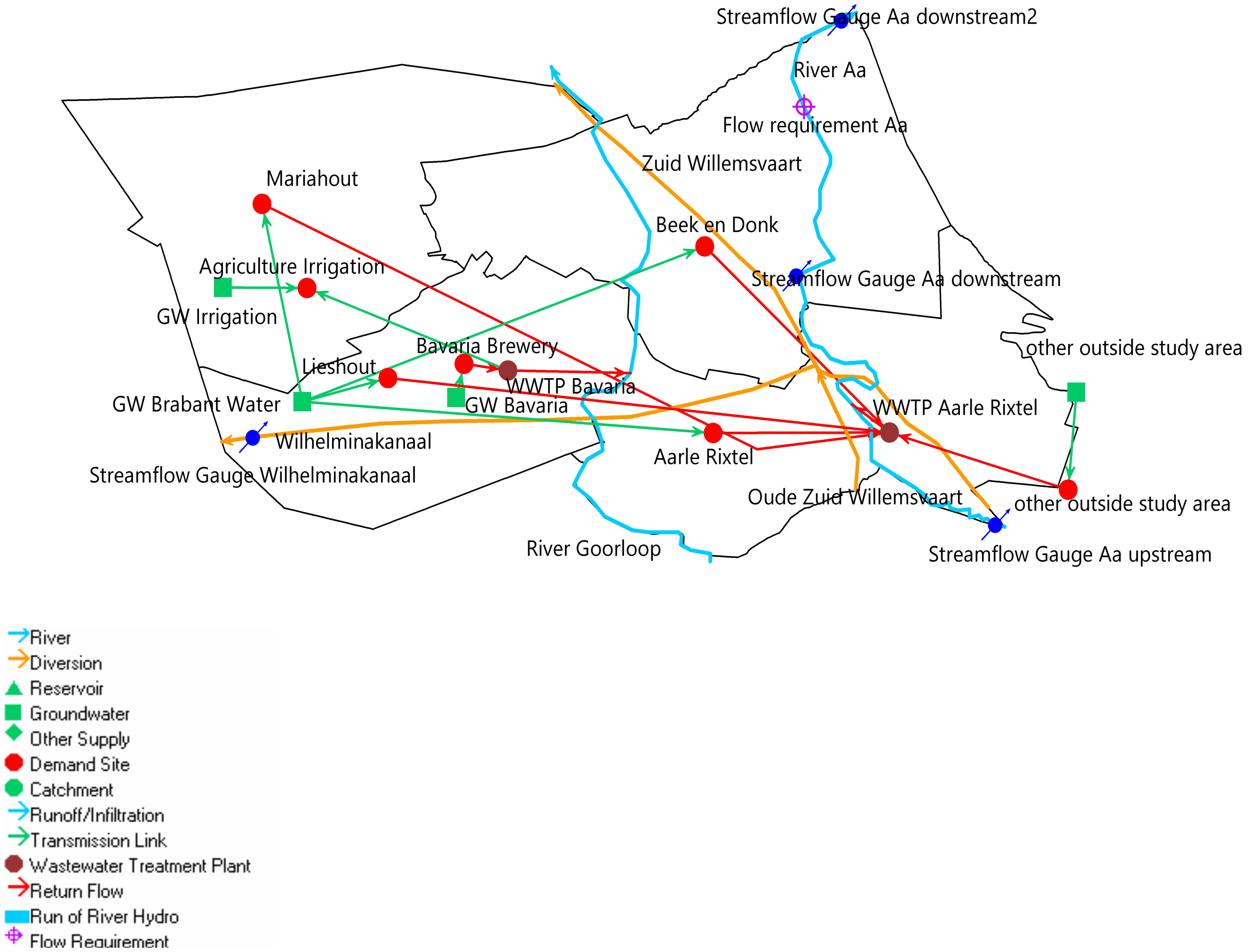

FIGURE 4: SCHEMATIC ELEMENTS IN WEAP MODEL FOR LAARBEEK.

Firstly, area boundaries were set for the municipality of Laarbeek. Consequently, demand sites were distributed within the catchment. A demand site is defined as a set of water users with a physical distribution system, that is all within a defined region. Demand data was not available for all individual sites in the area of boundaries; hence, the following four demand sites were established. The industrial facility was Bavaria Brewery, major cities (Mariahout, Lieshout, Beek en Donk, Aarle Rixtel), and irrigation districts for agricultural use. Demand site *other outside the study area* is outside the area of boundaries; however, the effluent from that demand site comes to WWTP Aarle Rixtel; therefore, it is on the schematic elements but not taken into consideration for the water demand calculations in Laarbeek.

Each demand site needed a transmission link from its source, and where applicable, a return flow links either directly to a river or WWTP. A WWTP can receive wastewater from multiple demand sites. A return flow link is a water that is not consumed at a demand site and can be directed to one to WWTP and surface nodes. The water consumption at the cities was assumed to be 0%; thus, the return flow nodes links are directly transported to WWTP Aarle Rixtel. WWTP Aarle Rixtel discharged treated effluent as a return link to River Aa. At the industrial site, water consumption was 40%. Therefore, 60% of the total demand was modeled as a return link directly into WWTP Bavaria. WWTP Bavaria removes pollutants and then returns treated effluent to River Goorloop and to via transmission link to the farmers for irrigation purposes.

The user-defined priority system defines the priority of allocations to demand sites. For each supply source, the supply site assigned a higher priority will always supply water when enough water is available. However, if the water is not enough, then the next supply site will be considered. In the WEAP model, priorities for demand sites within the basin were determined, as shown in Table 3, based on the Dutch Water Act's priorities.

TABLE 3: WATER ALLOCATION PRIORITIES SET IN WEAP MODEL ACCORDING TO THE DUTCH WATER ACT'S PRIORITIES (VAN RIJSWICK, 2015).

Demand site	Water allocation priority
Ecological Flows	1
Municipal	2
Industrial	4
Agricultural	4

Flow requirement node defines the minimum instream flow required at a point on River Aa to meet the river's environmental flow requirements.

Streamflow gauges, which are placed on the river, reach and describe points where actual streamflow measurements have been acquired and can be applied as points of comparison to simulate flows in the river. Streamflow data were added to River Aa in three locations. Due to data limitation, there was no streamflow gauge placed on River Goorloop. Streamflow gauge was placed on the Wilhelminakanaal. However, it was not used in another modeling in this research.

Groundwater characteristics were not taken into consideration in this research. It was assumed that there was enough groundwater to meet all the demand requirements in the watershed.

Water demand in the municipality of Laarbeek

The following water demand sectors were determined in the Laarbeek study area; municipality, agriculture, industry, and environment.

Municipal water

Municipal water demand included household water consumption in The Netherlands in 2016. According to the Dutch Drinking Water Statistics (2017), the following types of water uses were taken into consideration; bath, shower, washbasin, toilet flush, hand washing of laundry, machine washing of laundry, handwashing of dishes, dishwasher, food preparation, drinking coffee, tea and water, and other. It was estimated that water usage was 119,2 liter per person per day (Geudens & Grootveld, 2017). The detailed table can be found in Appendix II. The population of Laarbeek was 22.333 residents in 2019, which was used as population input in the WEAP model (CBS, 2020). The changes in population in Laarbeek within the past 10 years are shown in Appendix III.

Brabant Water is a drinking water company that provides water utilities in the region. The supply for drinking water was derived through groundwater abstraction (Geudens & Grootveld, 2017). The drinking water to meet the municipal water demand was extracted from the groundwater in the study area. Simultaneously, the municipal water demand was calculated based on the population size and average annual water use per person per day. All the other municipal demand such a watering public space was ignored. Besides, the monthly variations were assumed to be equal amongst the year.

EQUATION 2: MUNICIPAL WATER DEMAND

$$Municipal\ water\ demand = population\ size * water\ consumption$$

Agricultural water

In the study area, the only source of water to meet the agriculture demand was groundwater extractions by farmers. Due to limited data, the distribution of water for crop production was not determined based on the cultivated area, the type of crops, and planting and harvesting but on the groundwater extracted by the farmers in 2019. The data with boreholes coordinates, with the amount of water extracted was obtained from the water board Aa en Maas, and consequently exported and simulated in Quantum Geographical Information System (QGIS). Therefore, in 2019, the farmers extracted 1,2 million m^3 of groundwater for irrigation purposes. Besides, Bavaria Brewery gave to the farmers 0,5 million m^3 of purified industrial effluent that was used for irrigation (Bartholomeus et al., 2018). The crop's growing season was also a dry season from April 1 until September 30; thus, the following monthly irrigation rate was assumed, as can be seen in Figure 5. The total value of water needed for agriculture was inserted directly in the WEAP model; therefore, the model did not make any calculations. However, based on the monthly variation of irrigation, the water demand was distributed into the model.

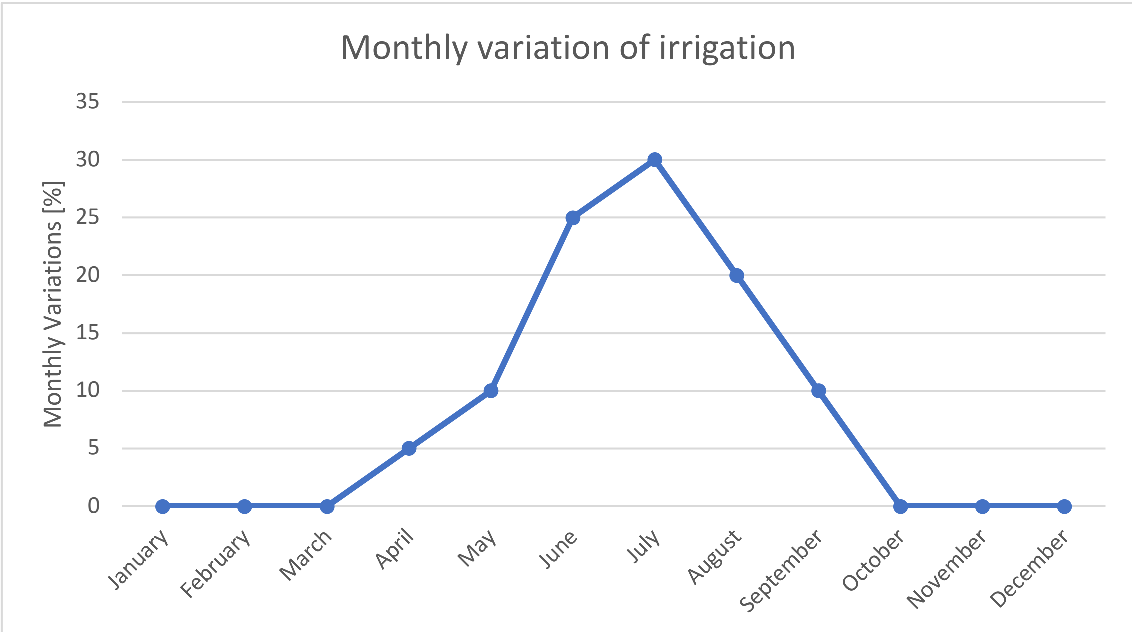

FIGURE 5: AN ASSUMPTION MADE IN THE WEAP MODEL ON MONTHLY VARIATION OF IRRIGATION IN THE CATCHMENT.

Industrial water

The industrial water demand was for Bavaria Brewery. Bavaria is located in Lieshout. The company's annual use in 2019 of groundwater was 2,5 million m^3, and 1,5 million m^3 was returned to WWTP Bavaria Brewery. 1 million m^3 of treated wastewater was discharged via surface water to River Goorloop. The Bavaria Brewery wanted to use purified wastewater (effluent) with farmers and water managers to reduce water scarcity and contribute to an economically healthy agricultural sector (Bartholomeus et al., 2018). Therefore, The Bavaria Brewery tested sub-irrigation with industrial wastewater in the dry field and reused of 0,5 million m^3 of treated effluent in 2019 (Bartholomeus et al., 2018). The total demand for water needed for the brewery was inserted manually in the WEAP model; hence, the model did not make any calculations. Besides, the monthly variations were assumed to be equal amongst the year.

Environmental flow requirements

The minimum instream river flow requirement was simulated in order to check whether the environmental quality of River Aa is sustained. The *Flow requirement Aa* node was inserted on River Aa downstream. The ecological flow was set as a priority in the model, meaning the flow requirement was satisfied before other system requirements. The minimum instream flow requirement was set to be based on the results of the environmental flow requirements. After entered as data on the specified point on the river the WEAP model carried out the simulations using the following equation:

EQUATION 3: ENVIRONMENTAL FLOW

$$EFRs_{downstream} = Streamflow_{upstream} + DS_{ReturnFlow} + WWTP_{ReturnFlow}$$

Where, EFR means Environmental Flow Requirements; DS - demand site; WWTP - Wastewater Treatment Plant.

The results of the simulated calculations showed the Unmet Instream Flow Requirement, which is the difference between the instream flow requirement and the amount actually delivered was compared with different scenarios.

Water quality modeling

Water quality was modeled in WEAP for River Aa. Due to data limitations, the water quality of the River Goorloop was not analyzed in this study. Moreover, total nitrogen and total phosphorous concentrations were studied. It was decided to use these two variables because the data was available, and the selected area of boundaries was mainly an agriculture site. Total nitrogen and phosphorous are typical pollutants in the Dutch surface water in these regions. Nitrogen and phosphorous are conservative parameters in the WEAP model, meaning there is no decay of these constituents. The instream river concentration will be computed using simple mixing and weighted average of the concentration from all inflows (Sieber & Purkey, 2015).

The typical concentration of total nitrogen and phosphorous in the Dutch surface water in the agricultural sites were taken from the literature and inserted in the river head flow and streamflow gauge upstream before the purified effluent goes into the river. The river head flow and streamflow gauge upstream had the following concentrations of 3,5mg/l of total nitrogen and 0,4mg/l of total phosphorous (RIVM, 2016).

The water quality simulation's primary purpose was to check whether the river water quality will change and how throughout the different scenarios; therefore, the downstream point (Flow requirement Aa) was chosen to be compared with different scenarios. The location is placed after the discharge point on the river Aa; hence, it could be seen if adding the purified effluent from WWTP Aarle Rixtel will change the quality of the river.

In Laarbeek, there were two WWTPs. WWTP Bavaria treats the effluent from the industrial processes of the brewery. However, there was a lack of detailed data about WWTP Bavaria Brewery. Therefore, the primary focus was the use of the WWTP Aarle Rixtel. WWTP Aarle-Rixtel purifies the wastewater from households and companies in the municipalities and residential centers; Aarle-Rixtel, Bakel, Beek en Donk, Boerdonk, Deurne, Elsendorp, Handel, Helmond, Gemert, Lieshout, Mariahout, De Mortel and De Rips (Waterschap Aa en Maas, 2014). In Table 4, the input data for the WEAP simulations regarding the WWTP Aarle Rixtel can be seen.

TABLE 4: WWTP AARLE RIXTEL – INPUT DATA INTO WEAP MODEL (Waterschap Aa en Maas, 2019).

WWTP Aarle Rixtel	2019
Max. hydraulic capacity	122,6e^6 m3/y
Effluent	24,6e^6 m3/y
Influent	24,6e^6 m3/y
N (total) removal rate	84,9 %
P (total) removal rate	90,4 %
Pollution inflow at WWTP **N (total)** **P (total)**	 1.099.386 kg/y 171.918 kg/y

WEAP model tracked water quality, including pollution generation at demand sites, waste removal at WWTP, effluent flows to the surface source, and water quality modeling in River Aa. Therefore, treated effluent from the WWTP Aarle Rixtel mixes with the river water. The concentration of a pollutant at the point of River Aa is calculated from the following mass balance equation (Sieber & Purkey, 2015):

EQUATION 4: SIMPLE MIXING MASS BALANCE.

$$c = \frac{Q_w c_w + Q_r c_r}{Q_w + Q_r} = \frac{M_w + Q_r c_r}{Q_w + Q_r}$$

c is the new concentration (mg/l)
Q_W is the inflow of wastewater
Q_r is the flow from upstream
C_W is the concentration of pollutant in the wastewater
C_r is the concentration of pollutant in the flow from upstream $M_W = Q_W C_W$, the mass of pollutant in wastewater.

3.5. Scenario development

The scenarios presented in this research illustrate alternatives in which the system's ability was compared to satisfy each scenario's water demands. Following the current and future development trends in the Meuse Basin and the potential impact of climate change, the following scenarios were analyzed. Since the time frame was limited in this study, it was assumed that reusing reclaimed water for irrigation and industrial purposes in the region is allowed and safe.

The scenarios have addressed different water allocation within the study area to meet all the water demand in 2019. In this research, nine scenarios were developed with the primary goal of limiting groundwater extraction to a minimum. The scenarios were shown in Table 5. Furthermore, check the River Aa water quality in terms of total nitrogen and phosphorous concentration. Subsequently, scenarios were used to check whether the environmental flow requirements were met or not. The climate characteristics and water demand stayed the same in all scenarios as in the base year. However, the water supplies to demand sites had been changed.

Scenarios 1 and 2 were not connected to River Aa quality because the River Aa abstraction did not reuse the treated wastewater from WWTP Aarle Rixtel. The supply preference 1 aims that all the necessary water to meet the water demand will come from that supplier. However, the ultimate goal is to meet all the water demand.

TABLE 5: WATER SUPPLIERS AND WATER USERS IN DEVELOPED SCENARIOS.

	Municipal demand	Industrial demand/ Bavaria Brewery	Agriculture/ Irrigation demand
Scenario 1	Groundwater as supply preference 1	Groundwater as supply preference 1	Treated effluent from WWTP Bavaria Brewery as supply preference 1; groundwater as supply preference 2
Scenario 2	Groundwater as supply preference 1	Treated effluent from WWTP Bavaria Brewery as supply preference 1; groundwater as supply preference 2	Groundwater as supply preference 1
Scenario 3	Groundwater as supply preference 1	Treated effluent from WWTP Aarle Rixtel as supply preference 1	Groundwater as supply preference 1
Scenario 4	Groundwater as supply preference 1	Groundwater as supply preference 1	Treated effluent from WWTP Aarle Rixtel as supply preference 1
Scenario 5	Groundwater as supply preference 1	Treated effluent from WWTP Bavaria Brewery as supply preference 1; groundwater as supply preference 2	Treated effluent from WWTP Aarle Rixtel as supply preference 1
Scenario 6	Groundwater as supply preference 1	Treated effluent from WWTP Aarle Rixtel as supply preference 1	Treated effluent from WWTP Aarle Rixtel as supply preference 1
Scenario 7	Rive Aa abstraction as supply preference 1	Treated effluent from WWTP Aarle Rixtel as supply preference 1	Treated effluent from WWTP Aarle Rixtel as supply preference 1
Scenario 8	Rive Aa abstraction as supply preference 1	Treated effluent from WWTP Bavaria Brewery as supply preference 1; groundwater as supply preference 2	Treated effluent from WWTP Aarle Rixtel as supply preference 1
Scenario 9	Groundwater as supply preference 1	Groundwater as supply preference 1	Treated effluent from WWTP Bavaria Brewery as supply preference 1; treated effluent from WWTP Aarle Rixtel as supply preference 2

4. Results

The main findings of the research are described in this chapter. The results were obtained based on the research and sub-research questions. Firstly, environmental flow requirements are explained. Consequently, relevant water users and supplies were determined, and the total groundwater use in the study area. The chapter continues with newly developed scenarios and their analysis in order to minimize groundwater extraction. Subsequently, water quality in River Aa was simulated based on total nitrogen and total phosphorous concentration. Following, the effect of the wastewater reuse on natural water availability in the stream.

4.1. SQ1: What are the environmental flow requirements in the selected catchment?

The environmental flow requirements (EFRs) are the result of the quantification of water necessary to sustain the riverine ecosystem. It was calculated from the hydrological method Q90. The Q90 was the flow exceedance of 90% of the period of 2019, with discharge measurements every 15 minutes. Only the Q90 of River Aa was calculated, as for the River Goorloop, data availability was too limited. The Flow Duration Curve performed in Microsoft Excel was used to determine Q90, which equals an EFRs of 2,5 m^3/s for the River Aa.

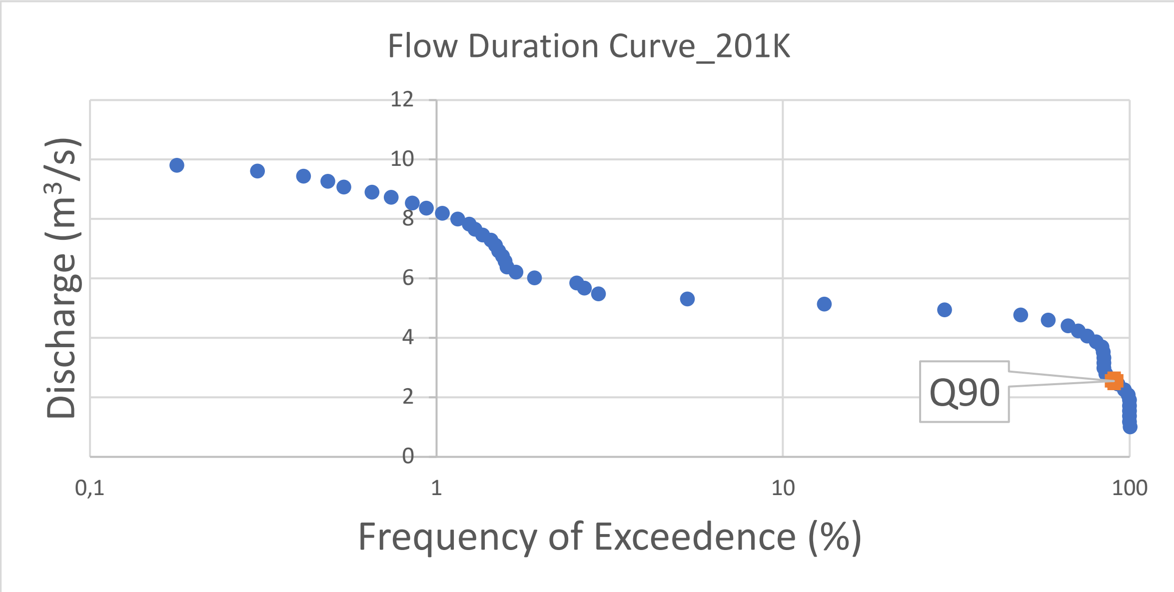

FIGURE 6: FLOW DURATION CURVE (FDC) AT THE STREAMFLOW GAUGE RIVER AA UPSTREAM FOR YEAR 2019.

4.2. SQ2: What are the relevant water supplies and water users, and their needs in the study area?

Figure 7 shows the groundwater abstractions in Laarbeek in 2019. All the water demand was encountered with total groundwater of 4.710.086 m^3. More than half were attributed to the industrial water supply following irrigation, with 26% and the drinking water supply of 21%.

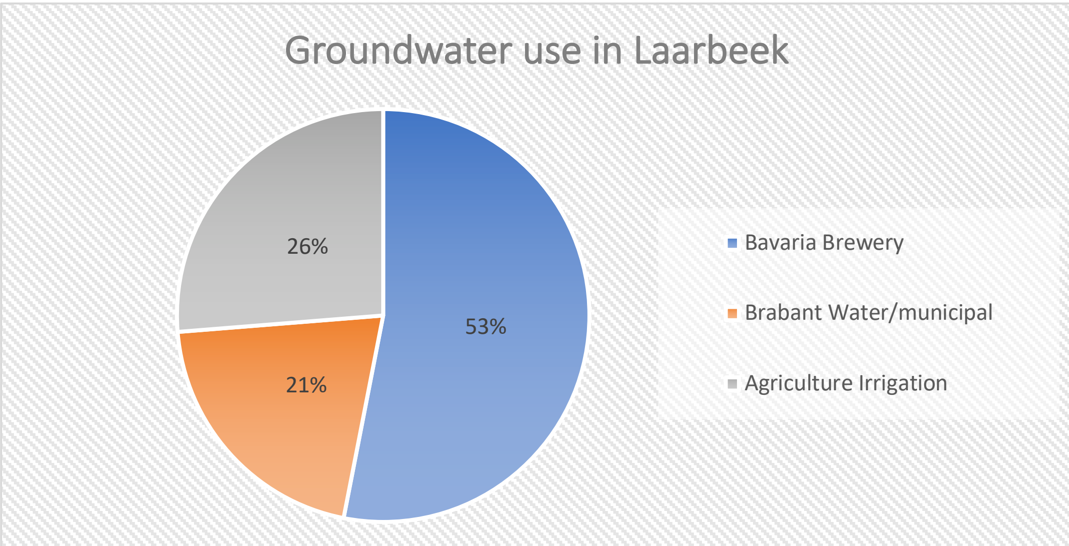

FIGURE 7: TOTAL GROUNDWATER USE IN LAARBEEK IN 2019 (CURRENT ACCOUNT).

Industrial water demand was accounted for only Bavaria Brewery. The reported volume of groundwater extracted in 2019 was 2,5 million m^3. The consumption of industrial water use was estimated to be approximately 40%, meaning that this volume was lost in the production. Therefore, the not consumed water was a runoff to WWTP Bavaria Brewery, which was 1,5 million m^3 of industrial influent. The wastewater was treated and discharged in the nearest river, Goorloop, as 1,5 million m^3. The 0,5 million m^3 of treated industrial effluent was given to farmers and reused as an irrigation source.

Municipal water demand in Laarbeek was supplied by the drinking water company, Brabant Water. Brabant water uses groundwater as a source for their drinking water. Thus, municipal water consumption was equal to nearly 1 million m^3/y. Furthermore, it was assumed that the municipal water demand is consumed by 0%. Therefore, the rest of the water, runoff, went to the WWTP Aarle Rixtel, where further was purified and discharged in River Aa.

Agricultural water demand corresponds to irrigation use in Laarbeek. It was deducted based on the groundwater that farmers extracted in 2019 in the study area and how much of the treated effluent water they had used. The total water demand was 1,7 million m^3.

4.3. RQ: How can the pressure on the groundwater resources be alleviated by making new connections between water users and water supplies?

In Table 6, the nine scenarios are shown with the source of water suppliers used. The current account represented the actual situation in the catchment in 2019. All the scenarios were developed for the 2019 water demand in the municipality of Laarbeek. Minimizing groundwater extraction in 2019 showed future development possibilities between different suppliers and users within the selected area. In the baseline scenario and all the scenarios, the water demand of the entire catchment was met. In each scenario, the water supply was shown as the percentage that was delivered to the user. The current account and two first scenarios did not include the reuse of the treated wastewater from WWTP Aarle Rixtel. Nevertheless, all the other scenarios included the reuse of treated effluent from WWTP Aarle Rixtel, at least one of the demand sites. Scenario 7 presented zero groundwater use in Laarbeek.

TABLE 6: RESULTS OF WATER DEMAND SUPPLIERS FOR DIFFERENT SCENARIOS TO MEET THE DEMAND OF MUNICIPALITY, INDUSTRY AND AGRICULTURE.

	Municipal demand	Industrial demand/ Bavaria Brewery	Agriculture/ Irrigation demand
Current account	100% groundwater	100% groundwater	29% treated effluent from WWTP Bavaria Brewery; 71% groundwater
Scenario 1	100% groundwater	100% groundwater	39% treated effluent from WWTP Bavaria Brewery; 61% groundwater
Scenario 2	100% groundwater	60% treated effluent from WWTP Bavaria Brewery; 40% groundwater	100% groundwater
Scenario 3	100% groundwater	100% treated effluent from WWTP Aarle Rixtel	100% groundwater
Scenario 4	100% groundwater	100% groundwater	100% treated effluent from WWTP Aarle Rixtel
Scenario 5	100% groundwater	60% treated effluent from WWTP Bavaria Brewery; 40% groundwater	100% treated effluent from WWTP Aarle Rixtel
Scenario 6	100% groundwater	100% treated effluent from WWTP Aarle Rixtel	100% treated effluent from WWTP Aarle Rixtel
Scenario 7	100% abstraction from River Aa	100% treated effluent from WWTP Aarle Rixtel	100% treated effluent from WWTP Aarle Rixtel
Scenario 8	100% abstraction from River Aa	60% treated effluent from WWTP Bavaria Brewery; 40% groundwater	100% treated wastewater from WWTP Aarle Rixtel
Scenario 9	100% groundwater	100% groundwater	10% treated effluent from WWTP Bavaria Brewery; 90% treated effluent from WWTP Aarle Rixtel

As shown in Figure 8, the lowest groundwater use is equal to zero for scenario 7, meaning a scenario that is only dependent on surface water and reuse of water for all sectors. The second-lowest groundwater extraction was obtained in scenario 6, where the groundwater was only used for municipal water demand. Furthermore, scenario 4 and 9 had the same amount of groundwater consumed; however, the source for irrigation water demand was different.

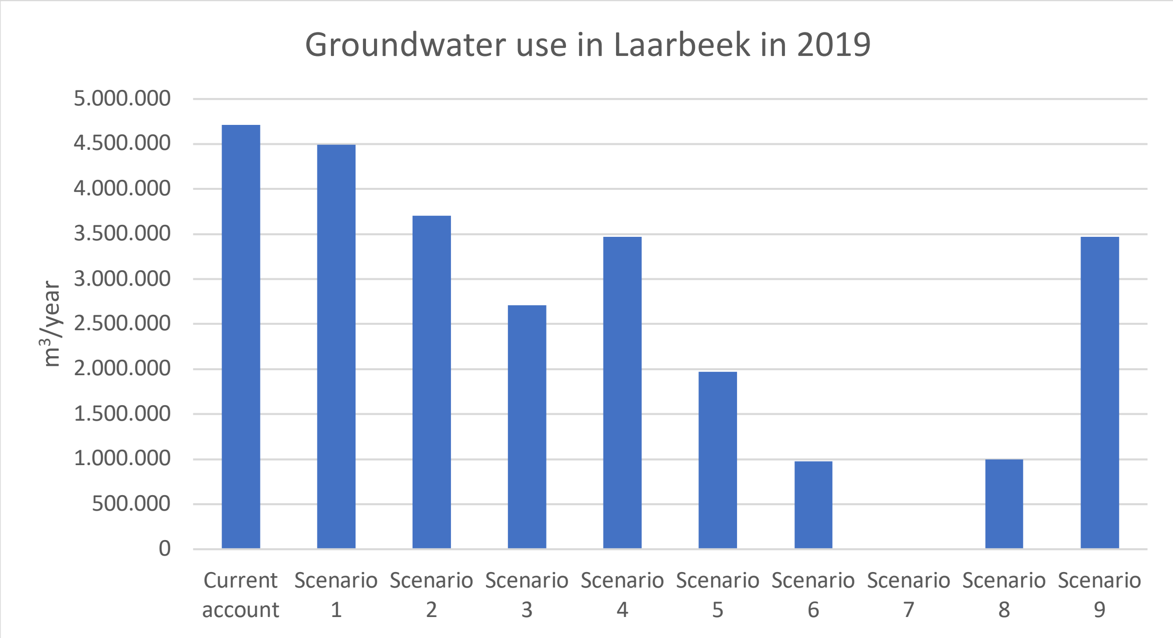

FIGURE 8: GROUNDWATER USE IN LAARBEEK IN DIFFERENT SCENARIOS FOR 2019.

4.4. SQ3: How does water quality in stream changes in different water allocation scenarios?

The quality of River Aa was examined at the *Flow Requirement Aa* location on the River Aa. Scenario 1,2, and the current account had the same water quality in River Aa. Because in each of these scenarios, there was no interaction within the River Aa streamflow; therefore, scenarios 1 and 2 are not in Figure 9. Besides, scenario 4 and 5 had the same results with regard to water quality in River Aa. Consequently, scenario 5 was not presented in Figure 9.

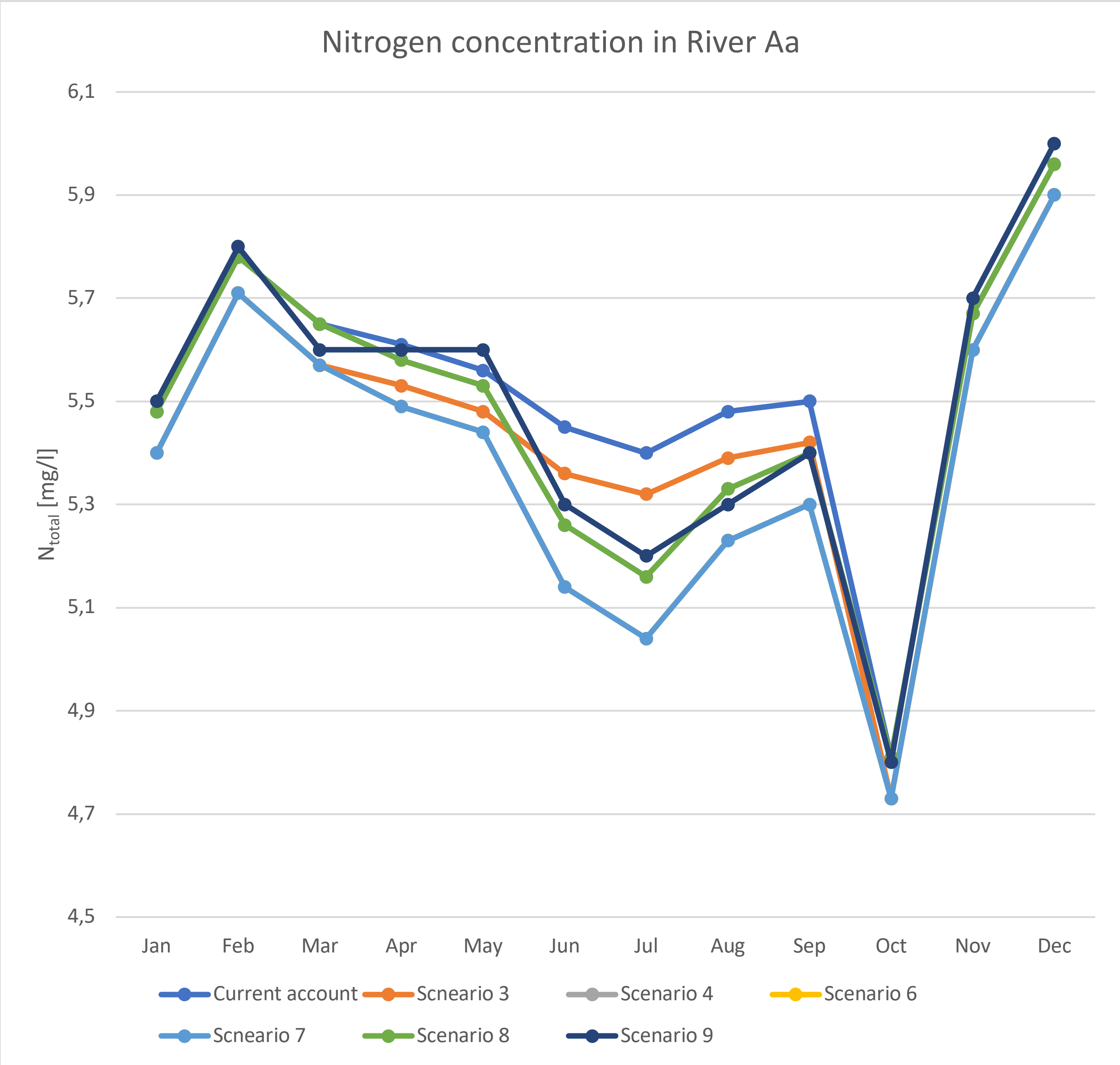

FIGURE 9: TOTAL NITROGEN CONCENTRATION IN RIVER AA IN 2019. NOTE THAT THE GRAPH STARTS AT 4,5 MG/L IN ORDER TO SHOW THE RESULTS BETTER.

All scenarios give the highest values in December and lowest in October due to streamflow variations in the River Aa. The highest variation in concentration differences is found in June-July because irrigation water demand required the most significant water amount in these months. Scenario 4 and 8 had the same nitrogen total concentration in the river. Thus, scenario 4 is not visible in Figure 9. Moreover, scenarios 6 and 7 also had the same nitrogen total concentration in the River Aa, which means that scenario 6 is not visible in Figure 9. The lowest total nitrogen concentration in River Aa was obtained in scenarios 6 and 7 within the entire year.

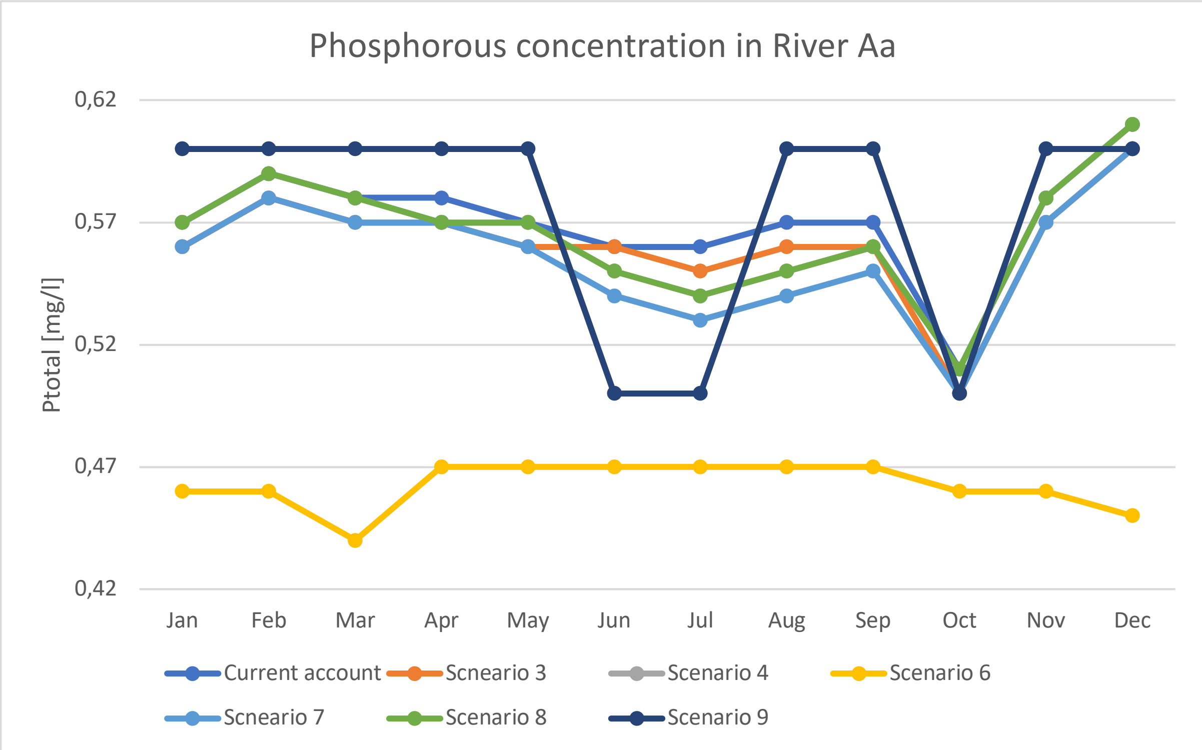

FIGURE 10: TOTAL PHOSPHOROUS CONCENTRATION IN RIVER AA IN 2019. NOTE THAT THE GRAPH STARTS AT 0,42 MG/L IN ORDER TO SHOW THE RESULTS BETTER.

Scenario 4, 5 and 8 had the same total phosphorous concentration during the whole year 2019. The lowest total phosphorous concentration throughout the year 2019 was achieved in scenario 6, as shown in Figure 10.

For most scenarios, the lowest values were found in October and the highest fluctuation between June and August. However, the differences are lower than with nitrogen concentration because the phosphorous concentration in the River Aa and the effluent is much smaller than nitrogen concentration.

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Figure 11 presented the unmet instream flow requirements of River Aa in 2019. All the scenarios did not meet the flow requirements in River Aa. In scenario 7 can be seen that was the highest unmet instream flow requirements. The lowest unmet instream flow requirement was simulated to be in the current account since any water from River Aa was extracted, and 100% of effluent from WWTP Aarle Rixtel was discharged into the river. The monthly results are presented in Appendix VI.

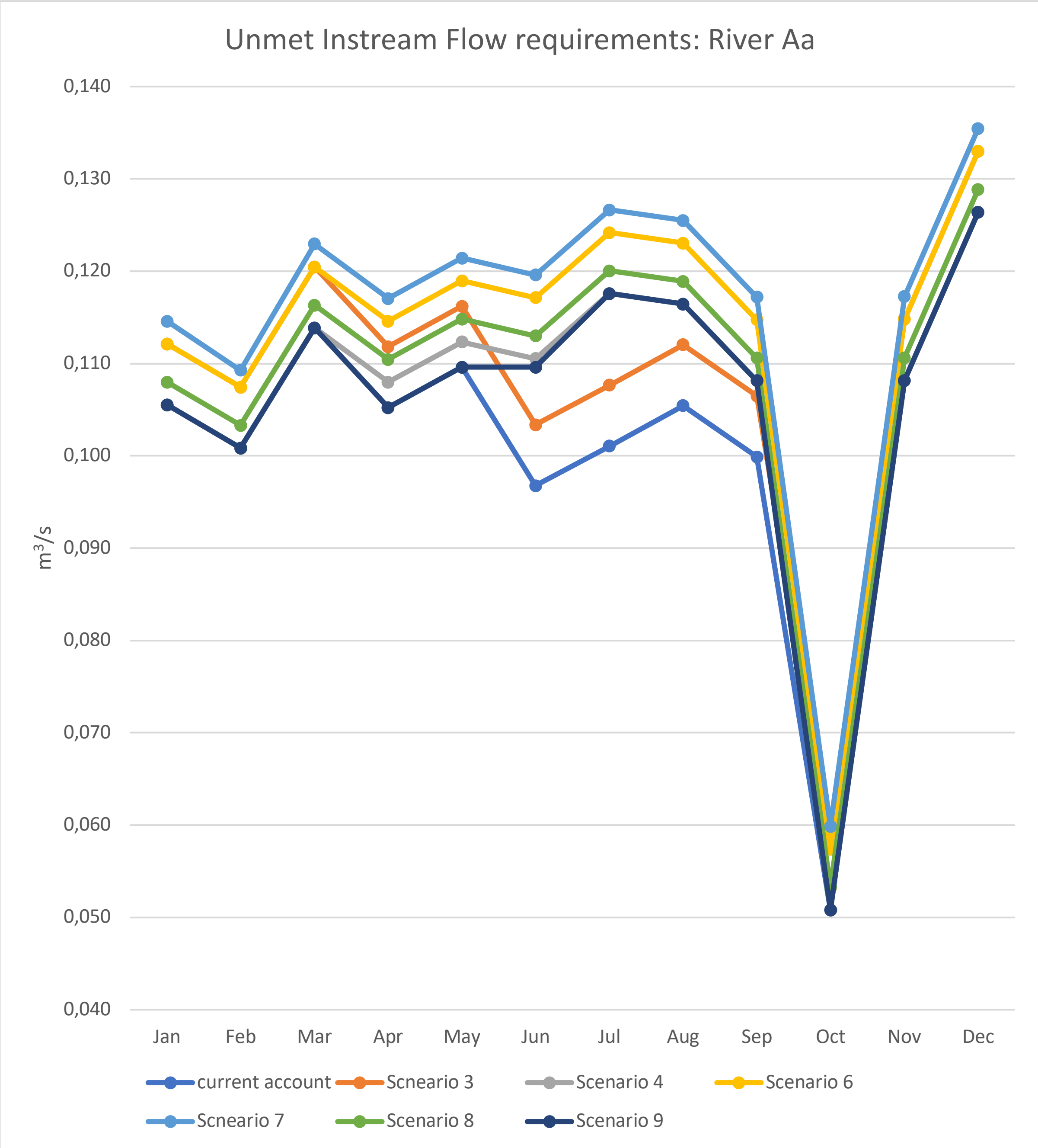

FIGURE 11: UNMET INSTREAM FLOW REQUIREMENTS IN RIVER AA IN 2019 AMONGST DIFFERENT SCENARIOS.

5. Discussion

5.1. Environmental flow requirements

River flow is the primary driver in maintaining a river's good ecological status (Poff et al., 2010). Human activities have impaired freshwater ecosystems through excess water withdrawal, river pollution, land-use change (including deforestation), and overfishing (Dudgeon, 2000). The flow targets are also assessed by considering specific exceedance percentiles of FDC derived from statistical analysis of daily discharge records (Smakhtin, 2001).

For instance, Canada and Brazil typically use Q90 discharge as applied in this study, while Australia and Taiwan are adopted as a minimum standard Q95 (Efstratiadis et al., 2014). In this research, it was calculated an environmental flow requirement of 2,5 m^3/y. This value cannot be compared with the literature because there are no such data.

A case study performed in the Acheloos River, located in Central Western Greece, represented the environmental flow requirement equal to 21,8 m^3/s, from the flow duration curves calculations, specifically the Q90. The Acheloos River is much larger than River Aa, with an average discharge of 136,9 m^3/s. The average annual discharge of River Aa is 2,6 m^3/s, the calculated environmental flow requirements for River Aa and River Acheloos cannot be compared. The Greece River's data input was of 5 years daily measurements while I used it for only one year (Efstratiadis et al., 2014). That might be a reason for some errors. Therefore, my calculated environmental flow requirement for River Aa might not be accurate because hydrological methods need long-term data sets of unregulated or naturalized daily flows (Smakhtin et al., 2006). I expect that the environmental flow requirement should be lower due to not take into account those variabilities.

5.2. Scenarios comparison

Scenario analysis was intended to identify the most feasible scenario that covers the minimum groundwater use. Therefore, while developing scenarios, alternative water sources were taken into accounts, such as purified effluent and River Aa abstraction. However, the calibration and validation of the model were not possible. Therefore, the best scenarios could not be chosen in this research.

The purpose of scenario 1 was to reuse the purified effluent from WWTP Bavaria Brewery as much as possible. Within this scenario was checked whether only the purified wastewater could supply the irrigation demand. The results proved that it is impossible. Nevertheless, the supply to agriculture demand for wastewater increased by 10% compared to the baseline scenario (current account). In the baseline scenario, farmers have already used the treated effluent from WWTP Bavaria Brewery for irrigation purposes, especially during droughts. The 39% of the total agricultural water demand could be supplied from treated wastewater from WWTP Bavaria Brewery. The maximum amount can be reused for the agricultural sector, based on the WEAP model. In scenario 2, the amount of reused wastewater from WWTP Bavaria Brewery for brewery processes is much higher than for the irrigation. It was due to the variations in monthly demand in both users. Bavaria Brewery needed water all year with the same variations while the agriculture needed water mainly in June and July.

Scenario 2 and 3 focused on changing the industrial water supply source. In scenario 2, the primary supply preference was treated effluent from WWTP Bavaria, while in scenario 2 was purified wastewater from WWTP Aarle Rixtel. It was established that 60% of the water demand of Bavaria Brewery could be met with reclaimed industrial water. However, in comparison, the Bavaria Brewery water demand can be met in 100% with the wastewater from WWTP Aarle Rixtel. The volume of the effluent from WWTP Aarle Rixtel is much higher than from the industrial WWTP. Nevertheless, the hazards to health and the environment from pollutants are also perceived as restrictions, in essence, bacteria, viruses, and emerging pollutants (Estevez et al., 2016).

Therefore, reclaimed wastewater is not used as a direct source of drinking water. According to European regulations, the direct use of treated wastewater for drinking water is not appropriate. Furthermore, since people directly consume the Bavaria Brewery's products, the collected wastewater cannot be used for consumption in production. Most of the reused wastewater can be used for other production processes, such as cooling and heating. Besides, treated wastewater could be reused to recharge aquifers that are accepted as a source of drinking water. Consequently, the minimum requirements, water intended for human consumption has to meet the standards from Drinking Water Directive 98/83/EC (DWD) in order to recharge the aquifers. However, this study did not take into account the recharge of aquifers (Kirhensteine et al., 2016).

Scenario 4 concentrated on reusing the purified wastewater from WWTP Aarle Rixtel for irrigation site. All the water demands were met; therefore, it is possible to supply water for irrigation just with the treated effluent. Scenario 4 focused on the reuse of treated wastewater from the WWTP Aarle Rixtel for site irrigation. All water needs are met; therefore, it is feasible to provide irrigation water only with treated effluent. Also, in the Netherlands, the reuse of wastewater for irrigation is known. For instance, The Dutch waterboard "Schieland en de Krimpenerwaard," "Aqua-Terra Nova," and "PB Techniek" have been successfully managing the innovative AquaReUse facility since 2014. At this facility, wastewater and surface water are treated to produce irrigation water, which meets all the primary water quality requirements of horticultural farmers and their customers. The facility delivers water for irrigation purposes, such as vegetable crops and flowers (The European Commission, 2016).

In scenario 5, water demand for agriculture was achieved only with effluent supply from WWTP Aarle Rixtel. The municipal water supplier was not changed, and the Bavaria Brewery was reusing 60% of the industrial wastewater for their production purposes. In addition, it seems suitable to reuse this amount of industrial wastewater for Bavaria Brewery production since 60% of the total demand is going to the WWTP Bavaria. Therefore, water is not consumed by the customers but used for the production process such as cooling and heating. Subsequently, the irrigation water demand was met with just purified effluent from WWTP Aarle Rixtel (The European Commission, 2016).

Scenario 7 was the most suitable to minimize groundwater use because there was zero groundwater extraction in the study area. However, this is not yet feasible due to European standards. Perhaps in the future, wastewater will be treated following drinking water quality standards; hence, it could be reused in all sectors, including drinking water companies.

In scenario 8, the water abstraction from River Aa met the municipal demand, while the effluent from WWTP Aarle Rixtel was used to supply the agriculture site. Bavaria Brewery reused wastewater from their production, and the rest extracted from groundwater, which was nearly 40% of the total water demand.

Since the purified effluent cannot be used for drinking water purposes, the municipal supply was groundwater. Consequently, the Bavaria Brewery consumed almost 40% of the groundwater and the rest discharged into WWTP. Therefore, in scenario 9, 40% had to be up to drinking quality standards and regulation because it was for drinking use. Moreover, in the agricultural sector, the primary supply preference was set to be treated effluent from the WWTP Bavaria Brewery. However, only 10% was used to meet that water demand, and 90% was supplied by purified wastewater from WWTP Aarle Rixtel. It might be because WWTP Aarle Rixtel had much larger effluent than WWTP Bavaria Brewery. Therefore, the WEAP model allocated proportional water resources to the amount of total effluent.

TABLE 7: SCENARIOS COMPARISON.

Scenarios	Groundwater use [m^3/year]	Unmet Instream Flow Requirements River Aa [m^3/year]	Water quality Pollution loads in River Aa [kg/year]	
			P total	N total
Baseline/ Current Account	4,7e^6	3,8e^6	1,7e^5	1,6e^4
Scenario 1	4,5e^6	3,8e^6	1,7e^5	1,6e^4
Scenario 2	3,7e^6	3,8e^6	1,7e^5	1,6e^4
Scenario 3	2,7e^6	4,1e^6	1,5e^5	1,5e^4
Scenario 4	3,5e^6	4e^6	1,51e^5	1,53e^4
Scenario 5	1,9e^6	4e^6	1,51e^5	1,53e^4
Scenario 6	0,97e^6	43e^6	1,4e^5	1,4e^4
Scenario 7	0	44e^6	1,4e^5	1,4e^4
Scenario 8	0,99e^6	4,12e^6	1,51e^5	1,53e^4
Scenario 9	3,5e^6	4,9e^6	1,6e^5	1,55e^4

In all the scenarios, the water quantity and quality in the River Aa had changed due to the reuse of wastewater from the WWTP Aarle Rixtel. The lower the volume of wastewater discharged into the river, the better the water quality in terms of nitrogen and phosphorus concentration. However, the stream's unmet flow rate requirements increase with the lower volume of effluent.

In Table 7, the green rows represent the feasible scenarios in the municipality of Laarbeek according to current standards on wastewater reuse in Europe, as was mentioned before. Therefore, scenarios 8 and 5 have the most significant potential in the catchment to minimize groundwater use and protect the watershed's environmental value. As can be seen, the pollution loads in the River Aa for both scenarios were the same. However, in scenario 8, 9,3e^5 m^3/y of unmet instream flow requirements for River Aa was more extensive than in scenario 5. Nevertheless, scenario 8 showed that 9,7e^5 m^3/y of groundwater was used less compared with scenario 5.

Each scenario contains a total nitrogen concentration in freshwater below the EU standards of 50 mg/l. Nevertheless, these standards aim to protect drinking water resources. These are not regulations for the state of good water quality of the WFD or the prevention of water eutrophication (RIVM, 2016).

5.3. Limitations

The study did not take into account the financial analysis. Besides, the input data shows a high degree of uncertainty. The data from the Goorloop River was negligible. Therefore, it was not possible to simulate the water quality of the Goorloop River. The wastewater data from the WWTP Aarle Rixtel was for the entire year and did not include monthly measurements. When calculating pollutants' concentration, monthly fluctuations are significant because precipitation and temperature vary throughout the year. Groundwater data was also not available for the entire watershed. Input data for evapotranspiration was not included in this study. Additionally, the study did not cover any data on the WWTP Bavaria Brewery. Water quality modeling only simulates two parameters; total nitrogen and total phosphorus.

No data is available on the environmental flow requirements of the Aa River. The calculated results can also not be compared to the literature from other studies, as the average flow data required at least multi-year records.

Furthermore, municipal water consumption was assumed to be 0%. However, this number can be inaccurate, especially in the summer, when people drink a lot of water and water their gardens. Consumption in agriculture was estimated at 100%, which means no runoff to surface or groundwater.

The WEAP model has been used mainly in developing countries such as South Africa (Arranz & Mccartney, 2007). Not all countries have sewerage systems in the basin. Also, the model setup generally consisted of a large area with several watersheds within the model. Therefore, in developed countries like the Netherlands, the model is very limited. As the Laarbeek catchment area was very small, the model had many performance issues. Moreover, the model's capabilities were limited since there are already sewage treatment plants across the country.

WEAP is a modeling tool based on a large number of input data and is limited to a simple water balance algorithm (Höllermann et al., 2010). The WEAP modeling study in the municipality of Laarbeek is one of Europe's first studies on modeling different water allocation strategies rather than simulating future water demand and its availability due to climate change and population growth. Therefore, there is no literature available to compare the results.

5.4. Evaluation of WEAP model

Studies that have already applied WEAP in other contexts and river basins show highly satisfactory performance and usability (Andah et al., 2014; Droogers & van Loon, 2006; Hao et al., 2011; Höllermann et al., 2010; Juízo & Lidén, 2008; Mccartney & Arranz, 2007; Mounir et al., 2011; Sardar Shahraki et al., 2016). This software is regarded as a valuable tool for integrated water resources planning. Overall, this study supports decision making in water allocation because the model results help reveal potential solutions to alleviate the pressure on groundwater resources (Gao et al., 2017).

Unlike other models, WEAP offers scenarios analysis with an easy-to-use approach, providing an extensive range of model results in a simplified way. Besides, the model is a scalable tool and can be updated at any time, allowing future improvements in model performance. The WEAP model is a tool for integrated water resources management (IWRM) worldwide (Mounir et al., 2011; Tena et al., 2019)

The WEAP model scenarios can address a broad range of "what if" questions, such as: if population growth and economic development patterns change? What if groundwater is more exploited? What if reservoir operating rules are altered? What if ecosystem requirements are tightened? However, it can also address change in water allocation as it was made in this research (Sieber & Purkey, 2015).

Scenarios in WEAP incorporate any factor that can change over time, made up of those that may change because of different assumptions or particular policy interventions. The scenario analysis is highly valuable because the preliminary results modeled in WEAP can guide whether the study is fulfilling or not specific goals.

5.5. Recommendations

The findings of the environmental flow requirements for River Aa suggest several further courses of action to obtain a valid number. It could be done by using a larger dataset of the discharges and recalculating the environmental flow. Consequently, it is recommended to compare the use of different hydrological methods such as Q90, used in this research, and Tennant method, which identifies several levels of minimum flows based on defined proportions of the mean flow (Tennant, 1976).

There is a definite need for data expansion in order to perform better simulations in the WEAP model. Another important practical implication is that the current study area is small, and it needs expansion. Because for example, the influent to WWTP Aarle Rixtel comes mainly from the area outside the municipality of Laarbeek. Therefore, by using a more significant area boundary, the results will be more accurate.

Calibration and validation of the WEAP model are needed. A reasonable approach to tackle model calibration could be modeling the agricultural site as a catchment rather than a demand site. There are five methods to simulate catchment processes such as evapotranspiration, runoff, infiltration, and irrigation demands. A Rainfall-Runoff Method (Simplified Coefficient Method) is recommended. This method determines evapotranspiration for irrigated and rainfed crops using crop coefficients. The remainder of precipitation not consumed by evapotranspiration is simulated as runoff to a river or can be proportioned among runoff to a river and flow to groundwater via runoff/infiltration links (Sieber & Purkey, 2015).

It is recommended to use the MODFLOW model to simulate the groundwater characteristics in the study area. MODFLOW is suitable for predicting future aquifer conditions. MODFLOW calculates the amount of groundwater discharge determined based on the groundwater's hydrological analysis (Kim et al., 2008; Slaughter & Mantel, 2018). Besides, the aquifer recharge by purified effluent could be analyzed for the study area. The outcomes regarding the aquifer's rechargeability and the results of this research can be compared to estimate what is most feasible for the watershed. Whether reuse wastewater directly in industrial and agricultural sites or recharge the qualifiers, the groundwater table rises and allows users to continue to withdraw groundwater.

Moreover, field surveys and observations are recommended. They include participatory field observations of various objects in the watershed, streamflow measurements, water sampling, soil survey, data collection from gauging stations, and water abstraction rate assessment. Also, field farm survey, focus group discussion with the stakeholders of the entire study area. That information will help to build an essential database on the basin under study.

6. Conclusion

In conclusion, the pressure on groundwater resources in the municipality of Laarbeek can be alleviated by making new connections between water users and water supplies. It is essential that the purified effluent from WWTPs will be reused and stays in the area. The hypothesis was correct, stating that the new connections between water supplies and water users could decrease the groundwater extraction. This minimized the impact of water quantity and quality. It is also true that the cleaner the effluent water, the better the water quality in the natural system. The scenario analysis showed that reusing the effluent water for irrigation demand is feasible for the study area.

The study area's relevant water users are identified as follows; drinking water company (Brabant Water), industry, and farmers. Industrial water demand was accounted for only Bavaria Brewery. Consequently, the reported volume of groundwater extracted in 2019 was 2,5 million m^3. Municipal water demand in Laarbeek was supplied by the drinking water company, Brabant Water. Municipal water consumption was equal to nearly 1 million m^3/y. Agricultural water demand corresponds to irrigation use in Laarbeek. It was deducted based on the groundwater that farmers extracted in 2019 in the study area and how much of the treated effluent was delivered from WWTP Bavaria Brewery they had used. The total annual water demand was 1,7 million m^3.

Results from calculating the environmental flow requirements for River Aa, which were 2,5 m^3/s, were used in further simulations in the WEAP model. The outcomes provided that the environmental flow requirements are not met in the selected catchment.

In all the scenarios quantity of available water in River Aa and river water quality had changed when there was effluent reuse from WWTP Aarle Rixtel. As in the Netherlands, the river flow depends on the effluent that makes it flow, especially during the summer months. Therefore, if the wastewater is reused and not discharged into the river, the streamflow decreases. Since the WWTP does not remove 100% of pollutants, there is pollution release as a discharge into the river. If wastewater is reused, fewer pollutants are released. Therefore, the more treated wastewater is reused, the better the streams' quality in terms of nitrogen and phosphorous concentration.

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Appendices

Appendix I – Upstream streamflow River Aa

TABLE 8: UPSTREAM STREAMFLOW RIVER AA

Streamflow upstream River Aa m³/s												
year	month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2019	0,494	0,359	0,395	0,430	0,446	0,533	0,546	0,495	0,496	1,328	0,395	0,246

Appendix II – Drinking water consumption in the Netherlands

TABLE 9: DRINKING WATER CONSUMPTION IN THE NETHERLANDS (GEUDENS & GROOTVELD, 2017)

Household water consumption							
Year	1995	1998	2001	2004	2007	2013	2016
	liter per person per day						
Bath	9	6,7	3,7	2,8	2,5	1,8	1,9
Shower	38,3	39,7	42	43,7	49,8	51,4	49,2
Washbasin	4,2	5,1	5,2	5,3	5,3	5,2	5,2
Toilet flush	42	40,2	39,3	35,8	37,1	33,8	34,6
Hand washing of laundry	2,1	2,1	1,8	1,5	1,7	1,4	1,3
Machine washing of laundry	25,5	23,3	22,8	18	15,5	14,3	14,1
Handwashing of dishes	4,9	3,8	3,6	3,9	3,8	3,6	3,5
Dishwasher	0,9	1,9	2,4	3	3	2	2,5
Food preparation	2	1,7	1,6	1,8	1,7	1	1,2
Drinking coffee, tea and water	1,5	1,5	1,5	1,6	1,8	1	1,3
Other	6,7	6,1	6,7	6,4	5,3	3,4	4,5
Total	137	131,9	130,7	123,8	124	118,9	119,2

Appendix III – Population in the municipality of Laarbeek from 2010-2020

TABLE 10: POPULATION IN THE MUNICIPALITY OF LAARBEEK FROM 2010-2020 (CBS, 2020)

Year	Population of Laarbeek
2010	21.581
2011	21.532
2012	21.608
2013	21.767
2014	21.802
2015	21.913
2016	21.965
2017	21.942
2018	22.158
2019	22.333
2020	22.523

Appendix IV – Monthly total nitrogen concentration

TABLE 11: MONTHLY TOTAL NITROGEN CONCENTRATION (MG/L) IN RIVER AA

Monthly total nitrogen concentration mg/l												
2019	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Current account	5,48	5,78	5,65	5,61	5,56	5,45	5,4	5,48	5,5	4,81	5,67	5,96
Scenario 3	5,4	5,71	5,57	5,53	5,48	5,36	5,32	5,39	5,42	4,73	5,6	5,9
Scenario 4	5,48	5,78	5,65	5,58	5,53	5,26	5,16	5,33	5,4	4,81	5,67	5,96
Scenario 6	5,4	5,71	5,57	5,49	5,44	5,14	5,04	5,23	5,3	4,73	5,6	5,9
Scenario 7	5,4	5,71	5,57	5,49	5,44	5,14	5,04	5,23	5,3	4,73	5,6	5,9
Scenario 8	5,48	5,78	5,65	5,58	5,53	5,26	5,16	5,33	5,4	4,81	5,67	5,96
Scenario 9	5,5	5,8	5,6	5,6	5,6	5,3	5,2	5,3	5,4	4,8	5,7	6

Appendix V – Monthly total phosphorous concentration

TABLE 12: MONTHLY TOTAL PHOSPHOROUS CONCENTRATION (MG/L) IN RIVER AA

Monthly total phosphorous concentration mg/l												
2019	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Current account	0,57	0,59	0,58	0,58	0,57	0,56	0,56	0,57	0,57	0,51	0,58	0,61
Scenario 3	0,56	0,58	0,57	0,57	0,56	0,56	0,55	0,56	0,56	0,5	0,57	0,6
Scenario 4	0,57	0,59	0,58	0,57	0,57	0,55	0,54	0,55	0,56	0,51	0,58	0,61
Scenario 6	0,46	0,46	0,44	0,47	0,47	0,47	0,47	0,47	0,47	0,46	0,46	0,45
Scenario 7	0,56	0,58	0,57	0,57	0,56	0,54	0,53	0,54	0,55	0,5	0,57	0,6
Scenario 8	0,57	0,59	0,58	0,57	0,57	0,55	0,54	0,55	0,56	0,51	0,58	0,61
Scenario 9	0,6	0,6	0,6	0,6	0,6	0,5	0,5	0,6	0,6	0,5	0,6	0,6

Appendix VI- Monthly unmet instream flow requirements in River Aa

TABLE 13: MONTHLY UNMET INSTREAM FLOW REQUIREMENTS (M^3/S) IN RIVER AA

Monthly Unmet Instream Flow Requirements River Aa m^3/s												
2019	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
current account	0,106	0,101	0,114	0,105	0,110	0,097	0,101	0,105	0,100	0,051	0,108	0,126
Scenario 3	0,112	0,107	0,120	0,112	0,116	0,103	0,108	0,112	0,106	0,057	0,115	0,133
Scenario 4	0,106	0,101	0,114	0,108	0,112	0,111	0,118	0,116	0,108	0,051	0,108	0,126
Scenario 6	0,112	0,107	0,120	0,115	0,119	0,117	0,124	0,123	0,115	0,057	0,115	0,133
Scenario 7	0,115	0,109	0,123	0,117	0,121	0,120	0,127	0,126	0,117	0,060	0,117	0,135
Scenario 8	0,108	0,103	0,116	0,110	0,115	0,113	0,120	0,119	0,111	0,053	0,111	0,129
Scenario 9	0,106	0,101	0,114	0,105	0,110	0,110	0,118	0,116	0,108	0,051	0,108	0,126