Opportunities for creating abundance of drinking water

Research in the water domain to create a knowledge base for the creative industries; a collaboration between the World Design Embassy of Water and Design United

12-16-2020

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Summary

In this research, the availability of drinking water has been investigated to identify opportunities for the creative industry to contribute to challenges that occur in the water sector. There is a general perception that people use too much water in all sectors. Currently, governmental organizations ask water users to change their behaviour during periods of drought, by limiting permits for irrigation and asking households to reduce drinking water consumption. When looking at the yearly trend of water availability in the Netherlands, we see water shortages summer and spring and water abundance in winter and fall. This leads to the question whether there is sufficient water to sustain the current usage, even in dry periods, in the long-term. In this research, we will investigate how large these water abundances and shortages are and in what ways this abundance can be converted to sufficient water for end-users.

The province North Brabant is the research area in this report, because the partners of the Embassy of Water are located here. Drinking water is produced from groundwater in North Brabant; therefore, the groundwater system has been investigated in more detail. In an average year, more water is extracted from the ground than is infiltrated into the subsoil. In dry years, this imbalance is even larger. The largest extractors of groundwater are drinking water companies and farmers. Overall, there does not seem to be insufficient availability of water. A lot of rain in Brabant is quickly drained as surface water and is therefore note retained in the ground. Reducing the amount of drained water seems to be the obvious measure that could lead to an improved groundwater level in North Brabant.

Most groundwater is extracted by drinking water companies and agricultural users. From the amount of water that is supplied by drinking water companies, only a limited amount (2%) is used for human intake. Most drinking water is used for showering (41%) and toilet flushing (29%). Groundwater use by the industrial sector has decreased significantly over the years, due to alternative water sources and more efficient water use internally. As for the agricultural sector, the water use varies greatly from dry years to wet years. In dry years, twice as much groundwater is pumped for irrigation compared to average years, resulting in decreased groundwater levels in summer. As a result, the nature water demand cannot always be met in drought periods; less rainwater is retained in the soil and groundwater levels are too low for plant roots to reach.

There is currently no abundance of water in North Brabant. To move from the current water shortage to a water-abundant state, the groundwater conditions should be improved. This can be done by increasing the water infiltration in the soil and by reducing the amount groundwater extraction. When reducing the amount of groundwater extraction much attention should be paid on household users that use the most drinking water, as well as the agricultural usage. An abundant water scenario can also be created from the retention of water. Increasing the amount of water that is stored in the subsoil can help to increase the groundwater level. Challenges for the creative industry can be to find ways to influence customers' water behaviours and to contribute to the effective implementation of water storage in public spaces, households or on agricultural land.

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Glossary

Storages	A place in which water can be stored (e.g., lakes or the underground)
Fluxes	A process in which water is transported between storages (e.g., precipitation and evaporation)
Open water bodies	Significant accumulation of surface water (e.g., lakes or rivers)
Streamflow	The amount of water flowing in a river or stream
Precipitation	Any form of water vapor that falls from clouds (e.g., rain, hail or snow)
Evaporation	The process of water going from liquid water to water vapor
Aquifer	Underground layer in which water can be transported (e.g., sand or permeable rock)

1 Introduction

The Topsector Creative Industry is looking for ways in which they can contribute to the development of new methods and knowledge for important societal challenges. Top Knowledge Institute of the Creative Industries CLICKNL provided funding for 4TU research center Design United to do research in collaboration with the World Design Embassy of Water (EoW) of the Dutch Design Foundation. The aim is to provide a knowledge base for EoW for future design projects and to specify research challenges for the future within the 'Knowledge and Innovation Agendas' (Kennis- en Innovatieagenda's, KIA's) for the creative industry.

The focus of the combined Embassy of Water/DU research is rooted in the KIA mission of 'Energy transition & Sustainability': Circular economy: MMIP 1 design for circularity and MMIP 3: trust behaviour and acceptance. An important focus of this research is the limited availability of drinking water that resulted in the research focus how to create opportunities for creating abundance of drinking water.

Three researchers from Wageningen University and Research (WUR) and Delft University of Technology have performed a research of the state-of-the-art knowledge of the Dutch water system that provides new insights for this water system and opportunities for creating abundance. This study should serve as a knowledge basis for the creative industry to determine the relevance of working in different sectors of the water system and give additional context related to water use and availability in the Netherlands.

In the Netherlands, the years 2018, 2019 and 2020 have been dry (KNMI, n.d.-c) and problems with drought occurred during summer months in past years. The reasons for this are the high temperatures and low amounts of precipitation in summer and spring. The effects of these droughts for water users have been manyfold, consisting of among others:

- Prohibition to use surface water for irrigation (H2O, 2020)
- Request by water companies to users to use less drinking water, especially during busy times (Brouwer, van Aalderen, & Koop, 2020)
- Problems for shipping companies (Rijkswaterstaat, n.d.)

On the other hand, water levels in large rivers, like the Rhine and the Meuse, over the year did not decrease drastically. In the winter of 2018, these river levels even reached their highest in 8 years (NOS, 2018). Furthermore, the yearly precipitation trend in the past century has been upward (CBS, PBL, RIVM, & WUR, 2020), with higher increases in winter than in summer.

There is the general perception that people use too much water in all sectors. Currently, governmental organizations ask water users to change their behaviour during periods of drought, by limiting permits for irrigation and asking households to reduce drinking water consumption. When looking at the yearly trend of water availability in the Netherlands, it is found that we experienced both shortages and abundance in water over time. This leads to the question whether there is sufficient water to sustain the current usage, even in dry periods, in the long-term. In this research, we will investigate how large these water abundances and shortages are and see in what ways this abundance can be converted to sufficient water for end-users. The research questions in this research are as follows:

- Is there an abundance of water when looking at a yearly timescale?
- Can the water shortage and abundance be regulated, and how?

- Where are the opportunities to create water abundance?
- Where can creative professionals play a role in creating water abundance?
- What is the existing research in the field?

As the Dutch water system is not uniform, there is a difference in water availability and problems related to water depending on the designated area. By bundling hydrological information and mapping out the water supply and use in a particular area, we can get a picture of how the water system works in that area and identify the opportunities of creating/regulating water abundance. However, water systems are connected. Therefore, also choices made in neighbouring areas have an influence on the water availability of an area.

Due to the limited time available for this research, it was not possible to investigate all the different water systems in the Netherlands, so the focus is on the province of North Brabant, where most of the partners of the Embassy of Water are located, and the working area of water board *De Dommel* (Figure 1). The results of this report therefore do not apply to all regions in the Netherlands due to the large variety in precipitation, soil types and the water management measures in different regions in the Netherlands.

An important characteristic of the water system of Brabant is that there is a large area of high sandy soils. Provinces that have comparable high sandy soils are large parts of the provinces Overijssel, Gelderland, Limburg and small parts of Drenthe and Utrecht (Wing, Kernteam Zoetwatervoorziening Oost Nederland, & Kernteam Deltaplan Hoge Zandgronden, 2015). While the exact numbers for water use differ, the conclusions in this report are therefore also largely applicable to these areas. Problems that occur in these areas are different from problems that occur in lower provinces, like North Holland, South Holland and Zeeland.

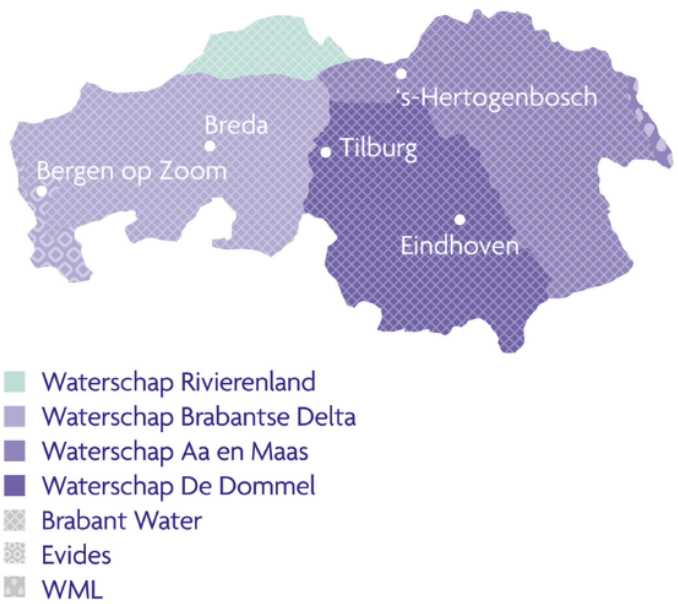


Figure 1. Water boards and drinking water companies in North Brabant (Onswater, n.d.)

2 Natural water balance of the Netherlands

In this section, the natural water system will be described shortly, after which the fluxes that are present in the Netherlands will be described.

The natural water system consists of fluxes and storages. The main storages in the Netherlands are open water bodies, like for example Lake IJssel, and groundwater storage. Fluxes in a water system can be either incoming or outgoing. Incoming fluxes are precipitation, which oftentimes falls as rain, and incoming streamflow from rivers and canals. Fluxes that are outgoing are evaporation and streamflow leaving the Netherlands. Other fluxes that exist in the Netherlands are water export. An example of this is water that is bottled in the Netherlands or water in food grown in the Netherlands but sold abroad. In the same way, water can be imported. A basic water system is displayed in Figure 2. While this is a Figure for a general system, the processes displayed also apply to the Netherlands.

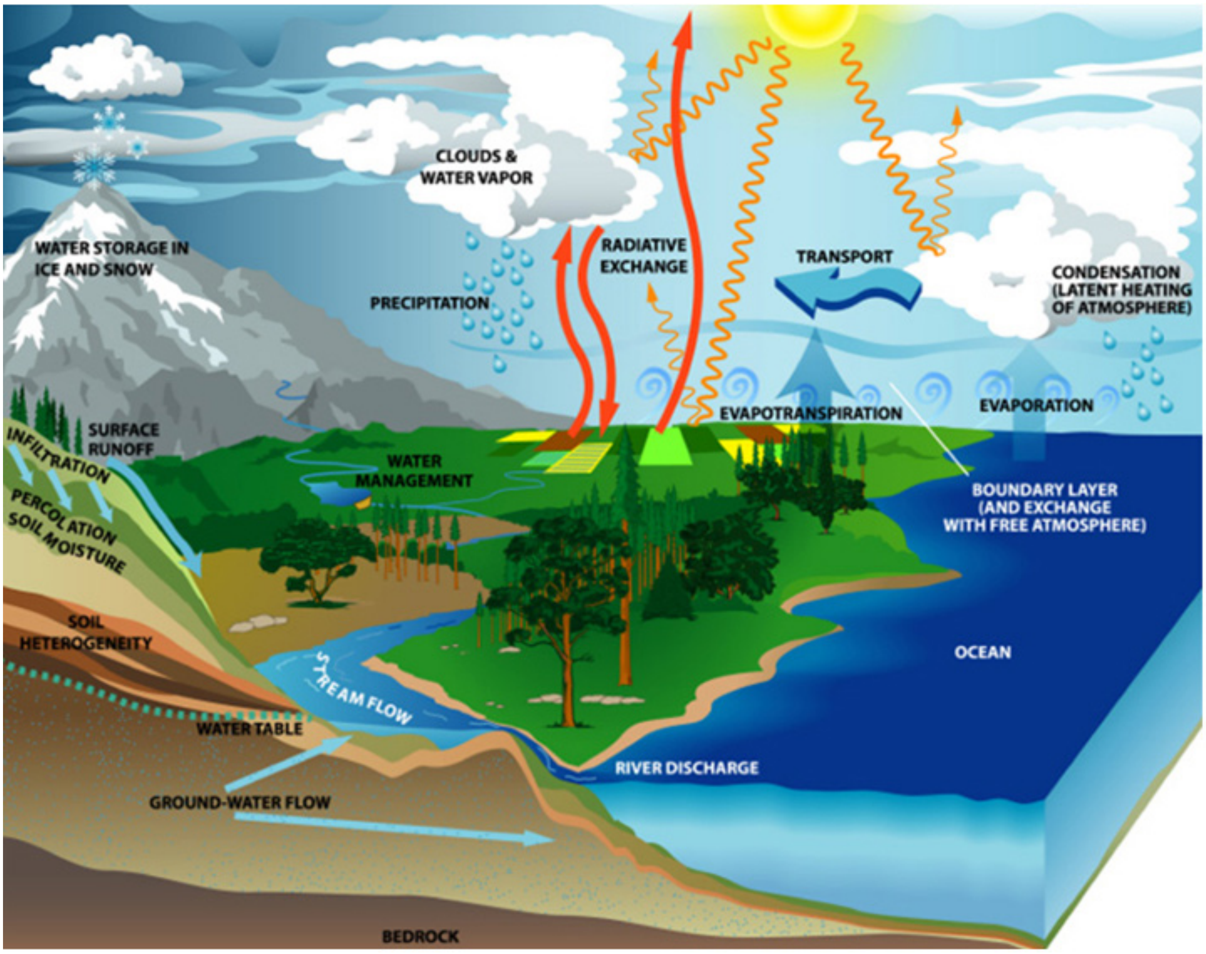


Figure 2. Overview of a water system (NCAR, n.d.)

In Table 1 an overview of the water balance for the Netherlands is displayed (Klijn, van Velzen, ter Maat, & Hunink, 2012). This table shows that in an average year the total precipitation is larger than the sum of evaporation and usage. Therefore, there is more outflow to the sea than incoming streamflow. However, in a very dry year, 1976, the amount of incoming streamflow is lower than the outflow to the sea. This means that the precipitation was not sufficient to account for evaporation and water usage. This does not necessarily have to be a problem when the incoming streamflow is sufficient. Incoming streamflow may not always be sufficient in dry years, as in these very dry years a smaller amount of streamflow comes into the Netherlands. The result of this is that in these years, water needs to come from storages, like lake IJssel and groundwater.

Table 1. Water balance of the Netherlands. Adapted from (Klijn et al., 2012)

		Average [10^6 m^3] (mean 1971 - 2000)	Dry year (1976) [10^6 m^3]
In			
	Precipitation	29200	19700
	Rhine	70400	41500
	Meuse	7400	3500
	Other rivers	3300	1500
Total		110300	66200
Out			
	Evaporation	20700	19400
	Water use	2300	6000
	Outflow to sea	87300	40800
Total		110300	66200

3 Natural water balance for North Brabant and Dommel region

An investigation in water resources has been performed for the whole province of North Brabant in 2010 (Wentink, van Kasteren, & Konz, 2010). This investigation has been done for the year 2007. The result of this research has been summarized in a Sankey diagram, which can be found in Figure 3. A large amount of water coming into the system as precipitation was evaporated. This total evaporation sum consists of both evaporation and transpiration, often also called evapotranspiration (USGS, n.d.). Evaporation consists of soil evaporation, evaporation from open water, like rivers and lakes, and evaporation of water that is intercepted by vegetation, for example water on leaves of plants after a rainfall event. Transpiration is water that is transpired through the leaves of vegetation. Transpiration is necessary for plants, because it is required to transport dissolved nutrients essential for the survival and growth of plants. A large part of the total transpiration is by vegetation used for agriculture. The amount of transpiration differs quite a lot based on the season. In the summer, the amount of water a plant transpires is a lot larger than in the winter.

A limited amount of water is used in the 'technical system', in which water is treated and used by humans. Of the total incoming water (5.6 billion m^3), only 0.4 billion m^3 is used in the technical system (7.1%).

The year that has been used in this report (2007) is a wet year. In a dry year, like 2003, it is estimated that the demand for evaporation is almost equal to the precipitation. Furthermore, water usage will also be higher in these years. Therefore, the situation during a dry year may be different from the situation during a wet year. Several consequences for the water balance in a dry year will be a lower amount of groundwater replenishment and a reduced flow to surface water. As a result, water use for the 'technical system' may be restricted, which is what happened in past years. Based on the 'verdringingsreeks' in the Netherlands, this will initially affect shipping, because of reduced water levels, industry and agriculture, but may eventually have an effect on drinking water availability (Ministerie van Infrastructuur en Waterstaat, n.d.).

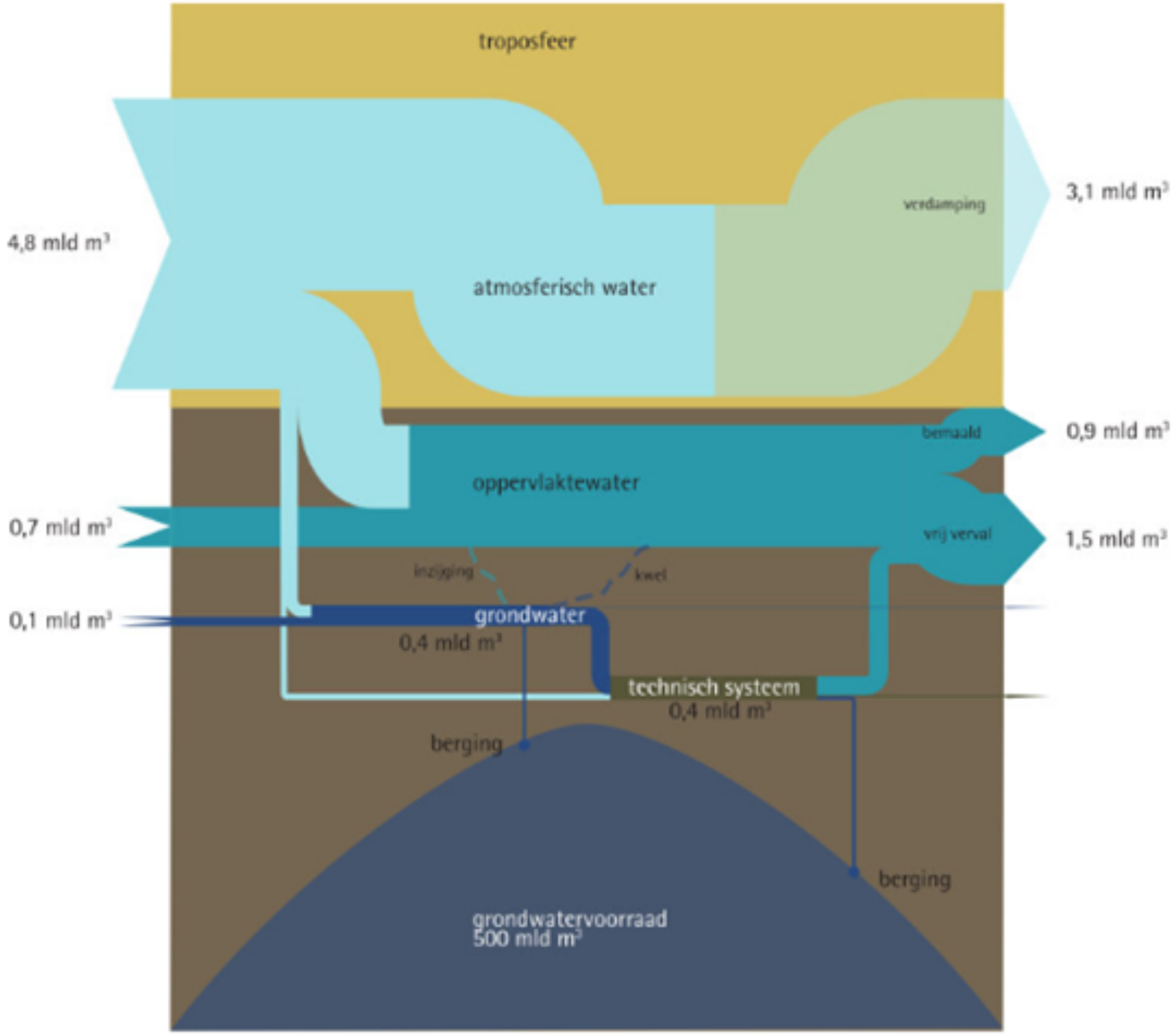


Figure 3. Sankey diagram for the natural water system in North Brabant (Wentink et al., 2010)

The Sankey diagram in Figure 3 focusses on one year. If multiple years need to be considered, different measurements should be looked at. The different important fluxes in a water system have been explained in Chapter 0. These fluxes are:

- Streamflow
- Precipitation
- Potential evaporation
- Groundwater extractions

The availability of these fluxes will be discussed in more detail below. In Figure 4 the different measurement locations present in the working area of the Dommel are given.

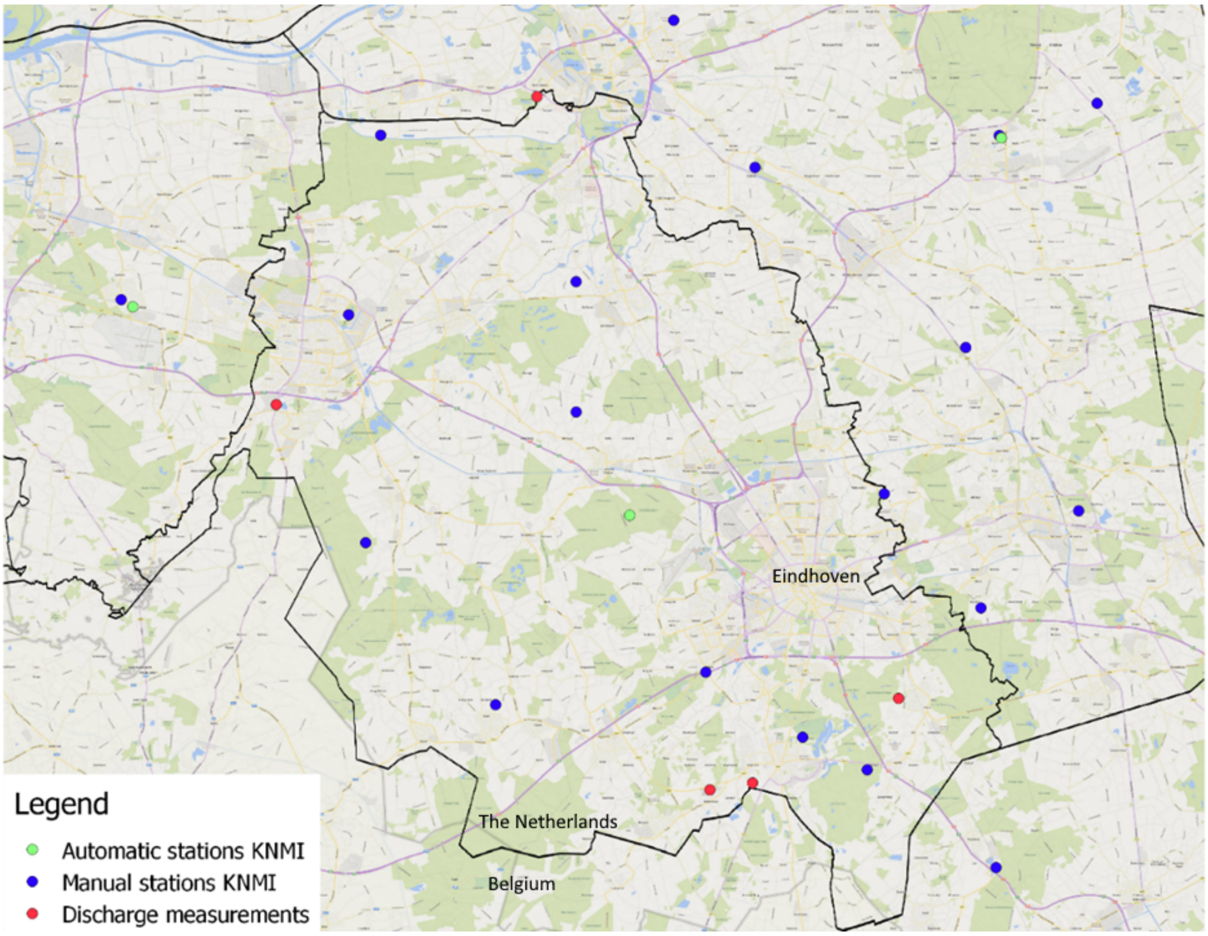


Figure 4. Overview of different measurement locations. The black line is the border of the working area of waterboard the Dommel. Automatic stations are stations where data is automatically gathered by the KNMI, consisting of both precipitation and potential evaporation. The manual stations are points where precipitation is measured daily. Data is from Hydrologic and KNMI (Hydrologic, n.d.; KNMI, n.d.-a, n.d.-b)

3.1 Streamflow

Streamflow, also called discharge (debiet), is the amount of water that flows through a specific section of a river or stream. This amount is not constant and varies in both place and time, due to water use and differing climatic conditions, like precipitation.

For discharge measurements, both incoming and outgoing streamflow are of importance. The difference between these flows is relevant, because this gives information about water use in the area. If the sum of incoming streamflow is larger than the outgoing streamflow, this means that more water than just precipitation is used in an area.

Incoming streamflow are flows that come from outside of the Dommel area, in this case mostly from Belgium. There are 4 measurement points that make up most of the incoming water (Wentink et al., 2010). These points are the Nieuwe Leij, Dommel, Tongelreep and Sterksels Kanaal. These are the discharge measurement points in the south in Figure 4. When looking at the outflow, the Bossche Broek contains most of the outflow of the area of the waterboard.

Data is available on an hourly basis with average discharges of that hour in m^3/s. These measurements can therefore be used in a seasonal or yearly analysis of water availability. In Figure 5, the in- and outflow for waterboard the Dommel is displayed over time. From this Figure it becomes clear that the total outflow is larger than the sum of the inflow. The mean difference between inflow and outflow is 10.6 m^3/s. On a yearly basis, this means that the amount of water that leaves the system as streamflow is larger than the amount of water that enters the system as streamflow. The difference is over 330 million m^3. If this is divided by the area of the waterboard (1.510.000 m^2), this equals approximately 200 millimetres. This is comparable to what was found in Figure 3, that a large part of precipitation in North Brabant becomes streamflow. A small sidenote is that there could be additional points of inflow coming in from Belgium. This would mean that there would be a smaller difference between inflow and outflow.

Furthermore, Figure 5 shows that the in- and outflow are a lot larger in the winter than in the summer. An exception are June and July of 2016. This can be explained by the fact that it was an exceptionally wet period for the eastern part of North-Brabant (KNMI, n.d.-e).

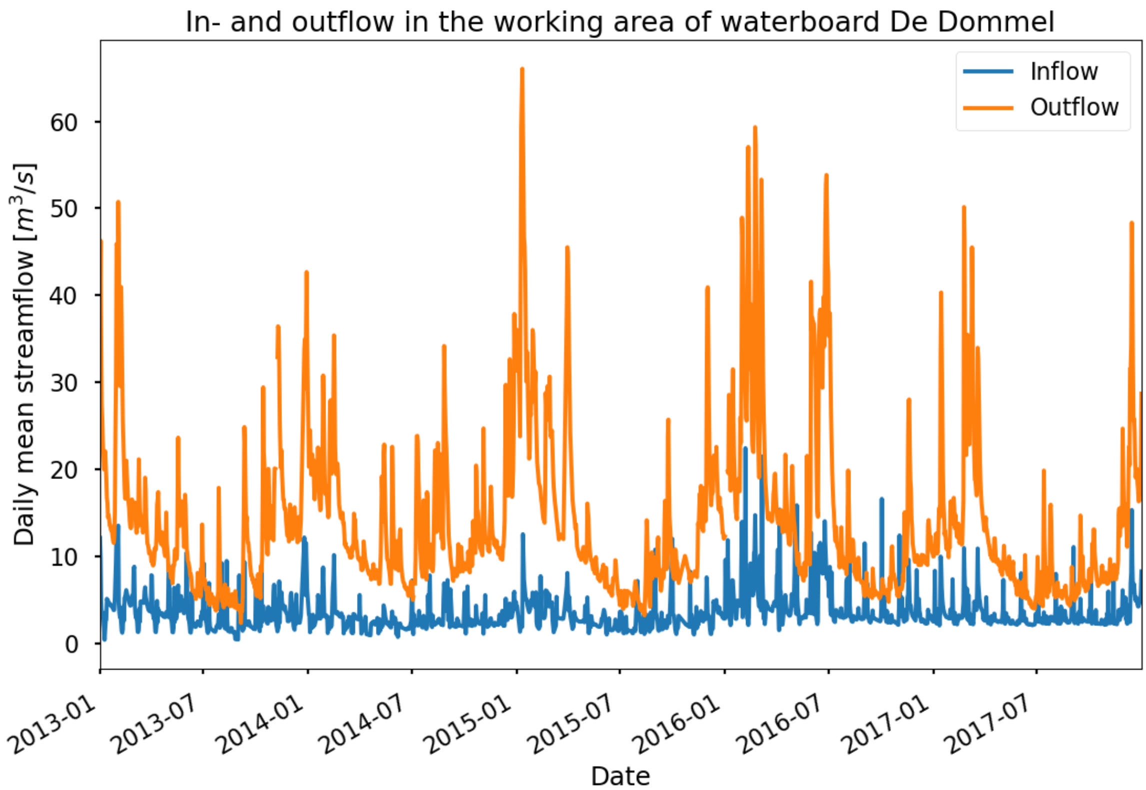


Figure 5. Daily mean in- and outflow for waterboard De Dommel. Inflow is the sum of 4 stations. Outflow is one station. Data from Hydrologic (Hydrologic, n.d.)

3.2 Precipitation

Precipitation is measured in two different ways in the Netherlands. First, there are automated measurements, which give hourly precipitation measurements. Secondly, there are manual precipitation measurement stations. The manual measurements are taken daily. This means that the data is given less frequently. However, for a seasonal analysis, this should be more than sufficient. There are 9 stations where precipitation data is registered in the Dommel area. Both the manual and automatic stations are displayed spatially in Figure 4.

The amount of precipitation can differ a lot between locations. Especially in the summer months, extreme precipitation events can affect small areas. As a result, locations that are close to each other, can have different annual precipitation amounts. To get a good estimate of the precipitation for the Dommel area, it is therefore good to consider multiple precipitation stations. In Figure 6, the precipitation is given for 3 stations in the Dommel area. As can be seen, there are quite large differences between the precipitation aggregates for the different stations. For example, the annual summed precipitation in Eindhoven is always lower than in Tilburg. This could be the result of the differences between the automatic and manual measurements. The other manual precipitation station, the station in Waalre, does not always show larger precipitation amounts than the station in Eindhoven. This could indicate that there is indeed a lower annual precipitation amount in Tilburg than in Eindhoven.

In the previous section, it was found that there was a mean yearly added streamflow of 200 mm. This means that almost a quarter of the yearly precipitation is drained to the surface water. While part of this water is needed for streamflow in streams, there is a possibility to hold some of this water.

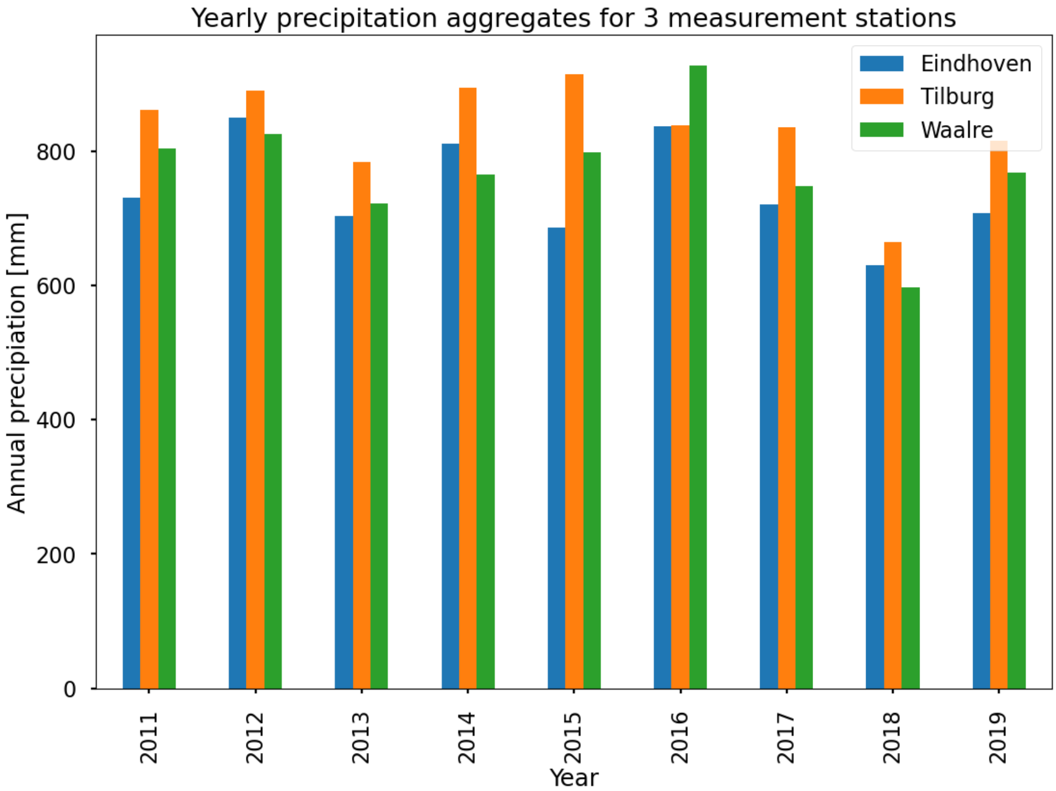


Figure 6. Annual precipitation measurements for 3 different measurement stations. 2020 has been excluded, because the complete year was not available. Adapted from KNMI (KNMI, n.d.-b, n.d.-a).

3.3 Evaporation

As it is hard to measure the actual amount of water that is evaporated, oftentimes potential evaporation is measured as a flux. Potential evaporation is the amount of water that can be evaporated if sufficient water is available. This is based on the temperature, wind and amount of solar radiation (KNMI, n.d.-d). Potential evaporation is not measured in a lot of places in the Netherlands. There is one station in the Dommel area that has data for potential evaporation, which is in Eindhoven. As potential evaporation data is a lot less heterogeneous than precipitation data, this is sufficient for an estimation of potential evaporation. Besides climatic conditions, the amount of evaporation is also dependent on the land use. For example, a large oak tree can transpire more than 150,000 litres each year (USGS, n.d.). Therefore, factors can be used to compensate for differences in land use, as is done in the report Waardecreatie met Water (Wentink et al., 2010).

A comparison for the potential evaporation and precipitation for the Eindhoven measurement station is displayed in Figure 7. From this Figure it becomes clear that oftentimes the amount of precipitation at the Eindhoven station is larger than the potential evaporation. However, in warm and dry years, like for example 2018 and 2019, the total amount of potential evaporation is higher than the precipitation. This is especially problematic for areas that are dependent solely precipitation and not on surface water, like for example high sandy soils. In these areas, the lack of precipitation cannot be compensated by use of surface water (Wing et al., 2015).

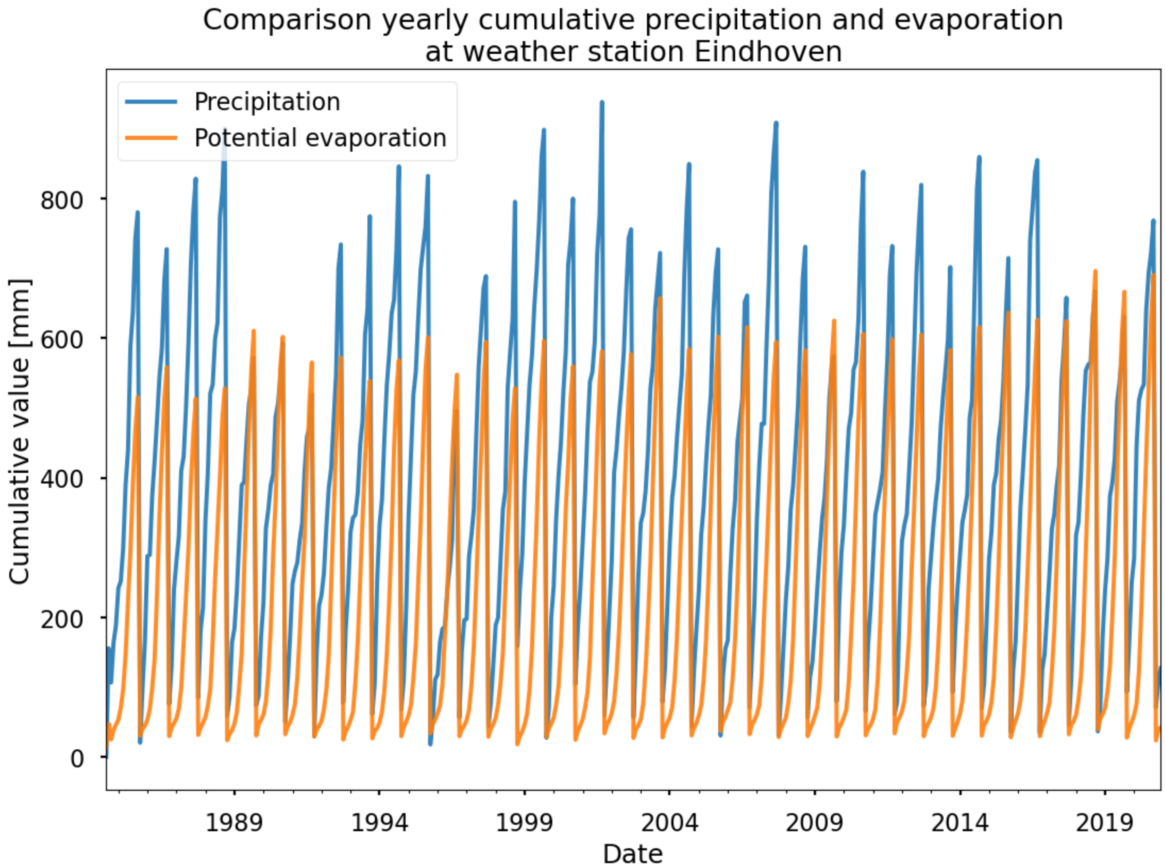


Figure 7. Comparison between precipitation and potential evaporation measured at the Eindhoven weather station. Data from KNMI (KNMI, n.d.-a)

When looking at the differences over the year between precipitation and potential evaporation, displayed in Figure 8, it becomes clear that in the summer the amount of potential evaporation is a lot larger than in winter. The variability of potential evaporation within a year is a lot larger than the variability in precipitation. This means that holding precipitation in the winter can be used to facilitate the higher evaporation in summer.

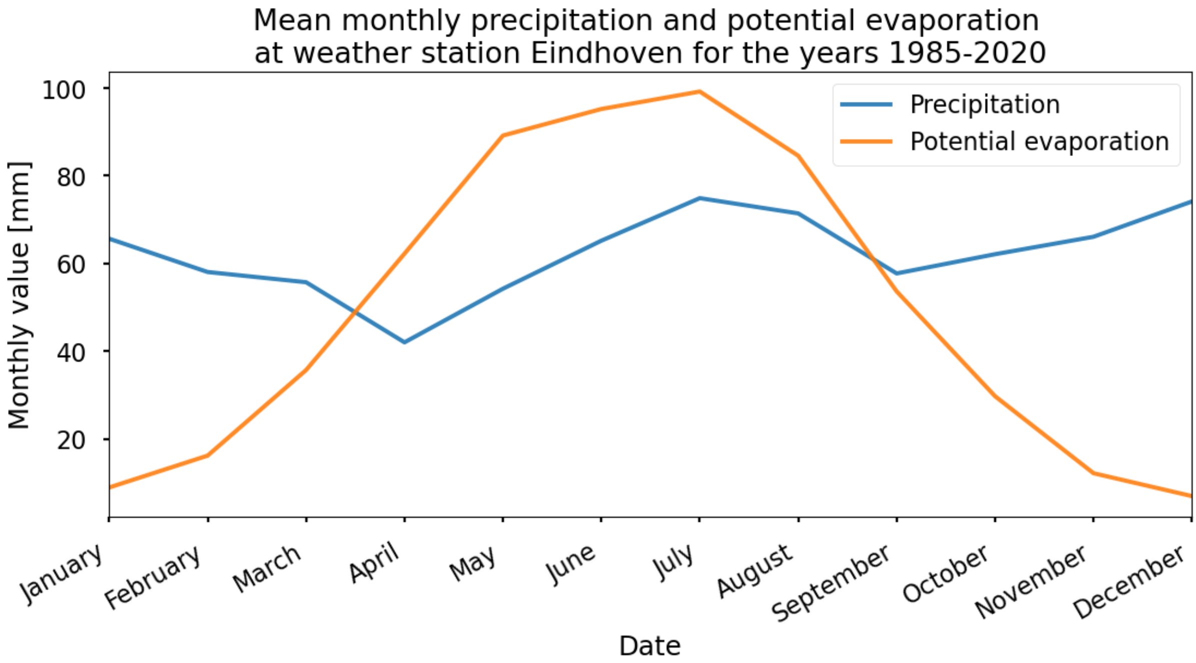


Figure 8. Mean monthly precipitation and potential evaporation over the year for weather station Eindhoven for the years 1985 – 2020. Data from KNMI (KNMI, n.d.-a)

3.4 Groundwater system

In the past years there has been a declining trend in the groundwater levels in North Brabant. This declining trend is visualised in Figure 9. In North-Brabant it is assumed that this decline is mostly due to increased drainage of water over the years (Wentink et al., 2010). Due to this increase in drainage, less water infiltrates into the ground, reducing the water level. However, other reports also suggest that reduced recharge due to changing land use (more forest) and increased crop yield also has a large effect on groundwater levels in North Brabant (Witte, Zaadnoordijk, & Buyse, 2019).

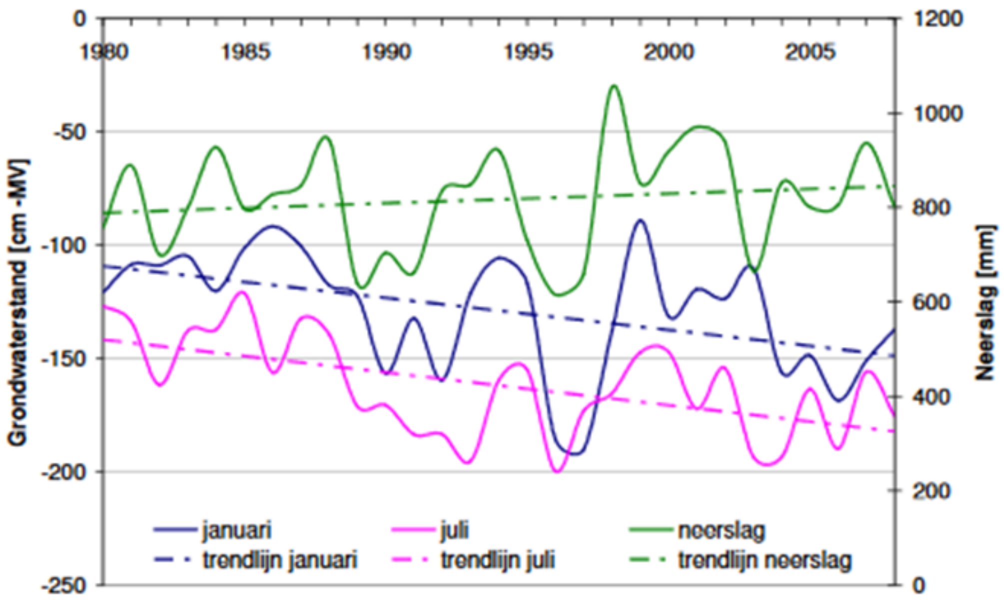


Figure 9. Trend of groundwater levels for 10 locations in the province of Brabant (Wentink et al., 2010)

In the working area of waterboard De Dommel, there are two aquifers (layers of ground that transport water) from which water is extracted (Figure 10). The shallow aquifer is used for irrigation, while the deeper aquifer is used for drinking water production. Water in an aquifer moves very slowly, resulting in long residence times. This is especially the case for the deeper aquifers, which contains water that has been there for over a thousand years.

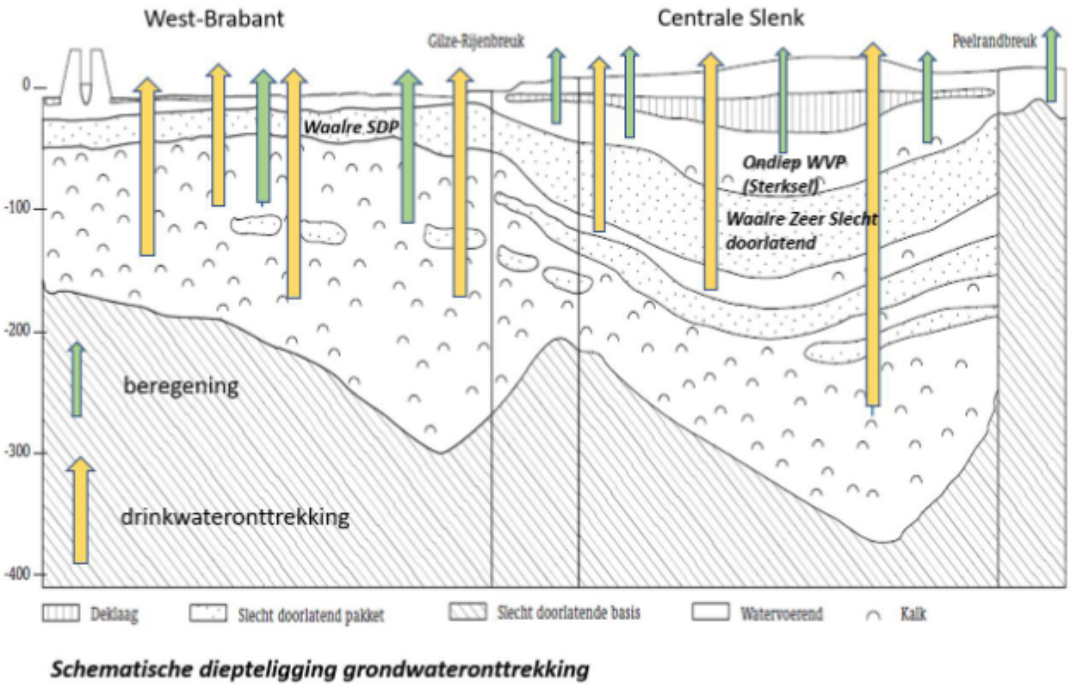
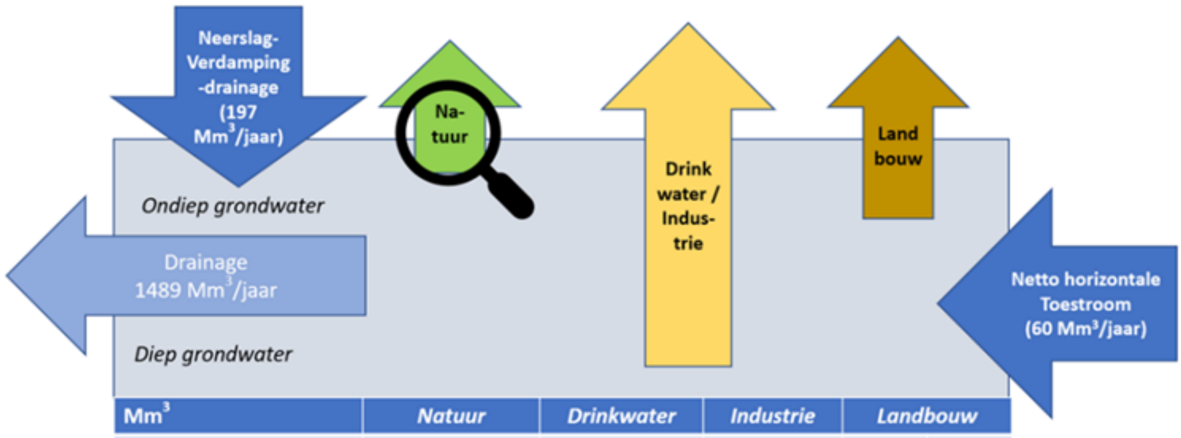


Figure 10. Groundwater extractions in the subsurface of North Brabant. Working area of the Dommel is located in the 'Centrale Slenk' (Deltares, 2020)

When looking at the groundwater balance in North Brabant, there is a precipitation surplus (precipitation minus evaporation) of approximately 1700 million m^3/year.

By dewatering and drainage, around 80% of surplus rainwater is removed via surface water from the province (approx., 1500 million m^3/year). Each year, around 260 million m^3 of water replenishes the groundwater supply in Brabant; 200 million m^3 of rainwater infiltrates into the deeper groundwater; and 60 million m^3 of horizontal groundwater from surrounding areas recharges the groundwater system in the province (Noord-Brabant, 2018). In Figure 11, this is also displayed schematically.



Mm^3	Natuur	Drinkwater	Industrie	Landbouw	
	kwel			beregenen	Vee/stal
Gemiddeld jaar (totaal)	50-60	200	30	40	20
Zomer gemiddeld jaar	-	100	15	40	10
Droog jaar (totaal)	-	210	30	100	20
Zomer droog jaar	-	110	15 (?)	100	10

Figure 11. Overview of the water balance terms of North Brabant (Deltares, 2020)

In the past years, the use of groundwater has exceeded the groundwater replenishment. It is estimated that for an average year, groundwater replenishment equals 260 million m^3, while groundwater extractions exceed 270 million m^3 (Deltares, 2020). This means that currently there is an imbalance regarding groundwater system in North Brabant. It is expected that if this current imbalance continues, eventually a new steady-state will be reached, with reduced groundwater levels.

The reason for this steady-state is that the lower groundwater levels will lead to a reduction in drainage of water and an increase in incoming water. These reduced groundwater levels will have a large influence on the ecological system for the province of North Brabant, especially for natural systems that are dependent on higher groundwater levels. In past summers, a reduction or complete drying up of streams has occurred, due to a combination of lower precipitation and low groundwater levels (Deltares, 2020).

The three largest players regarding groundwater extractions in Brabant are (Noord-Brabant, 2018):

- Drinking water companies (200 million m^3/year)
- Agriculture (40 million m^3/year)
- Industry (30 million m^3/year)

In recent years, the agricultural water use varied between 20 and 100 million m^3/year, depending on the drought in the growing season. For example, in the year of 2018 (a dry year), the agriculture sector extracted around 100 million m^3 groundwater for irrigation. In addition to the registered groundwater extraction, it is estimated that the unrecorded extraction points account for 23 to 32 million m^3 groundwater extraction per year (Deltares, 2020). The imbalance in groundwater system is even greater when taking the water into account that is required for nature. In a recent report (Deltares, 2020), it shows that the direct water requirement of nature accounts for 50-60 million m^3 of groundwater per year. As a result, the annual amount of groundwater extraction exceeds the total replenishment in Brabant, as can be seen in Figure 11.

When looking at the development of water use over time, displayed in Figure 12, it is clear that groundwater extractions for drinking water have stabilised in the past years. Groundwater extracted for irrigation varies by a lot. As stated before, this extraction can be up to 100 million m^3 per year in a very dry year. That means water extraction by irrigation can be almost half of the amount of water extracted for drinking water and therefore it can play a significant role in the reduction of groundwater levels.

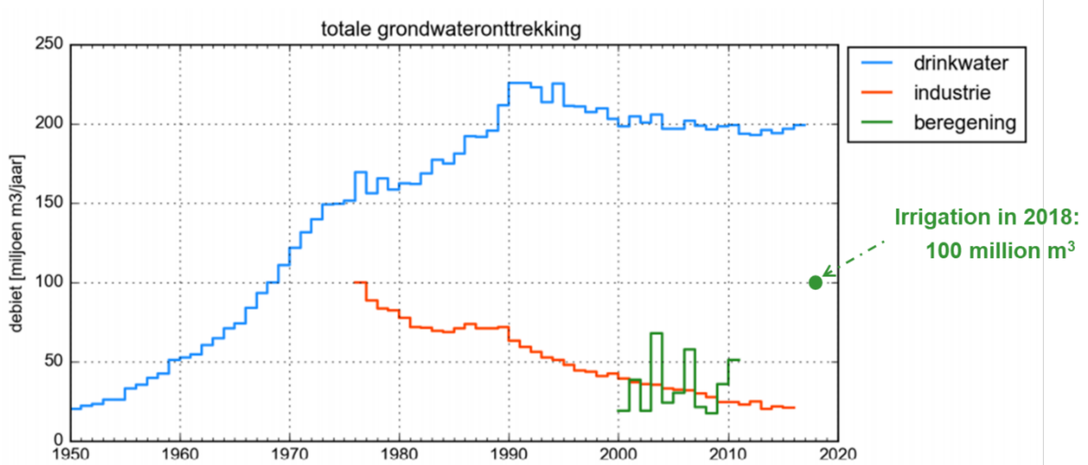


Figure 12. Annual registered amount of groundwater abstracted for drinking water, industry and irrigation (adapted from Noord-Brabant, 2018)

In the province of North Brabant, groundwater is the sole source of drinking water. When thinking about abundance, it is important to have a sustainable groundwater system. Therefore, a new balance with higher groundwater levels is required.

Given the above information, we propose two possible ways of thinking to improve the groundwater condition in North Brabant, namely increasing the groundwater replenishment and reducing the extraction of groundwater. As the main uses of groundwater are for drinking water and for irrigation, these are the two most important consumers to be considered when improving the groundwater situation. This is also displayed in Figure 13. Under the current conditions, sufficient water should be available to meet the water demand. However, if household demand increases and no measures are taken to store water in the ground, this could lead to problems.

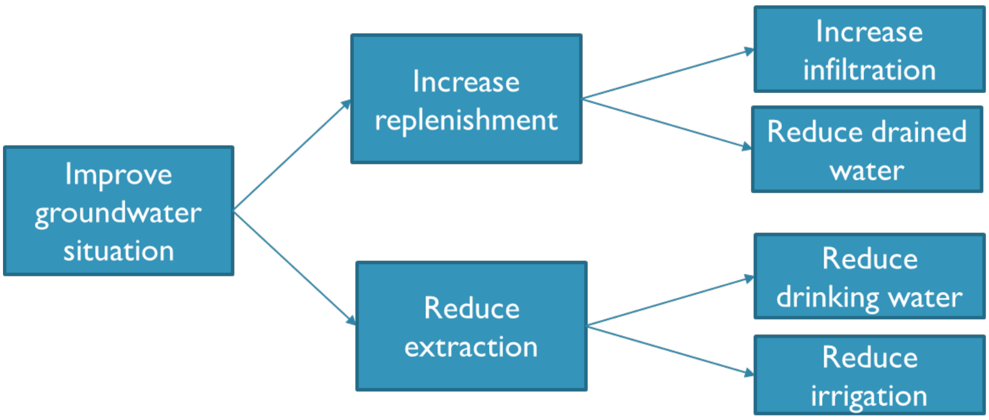


Figure 13. Possibilities for improving the groundwater levels in North Brabant

4 Anthropogenic water use in North Brabant

Figure 12 shows the changing pattern of groundwater use for drinking water, industry and irrigation in North Brabant over the years. The quantity of groundwater extracted for drinking water production increased greatly from the year of 1950 to 1990; after that, drinking water consumption experienced a decrease over ten years and has been stabilized around 200 million m^3/year after the year of 2000. The amount of groundwater used by industrial sectors has been decreasing since mid-1970s and the downward trend has slowed down since the year of 2010. Groundwater used by agriculture sectors differs greatly from year to year, depending on the climate of the year. In the following part of this chapter, the water use at homes, industry, agriculture and nature in North Brabant will be introduced in detail. Figure 14 shows the amount of groundwater extraction by each sector in Brabant. The current largest portion of groundwater is extracted for drinking water production in North Brabant.

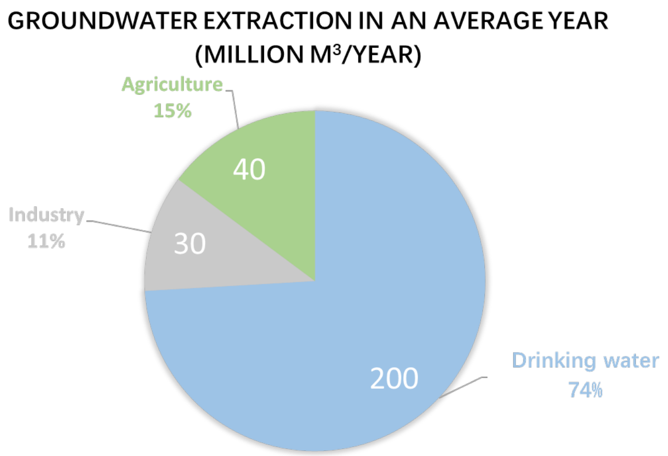


Figure 14. The amount of groundwater extraction by each sector in North Brabant

4.1 Water use at homes

In this part, the results of research on household water use in the Netherlands are used due to the lack of information on regional scale. Research of Vewin (2017) shows the overview of all sub-uses of drinking water at home (Figure 15). In total, domestic drinking water consumption equals to 119 L/person/day (Vewin, 2017). Most of the water is used for showering (41%) and toilet flushing (29%), followed by machine washing of laundry (12%); together they represent more than 80% of total household consumption per person.

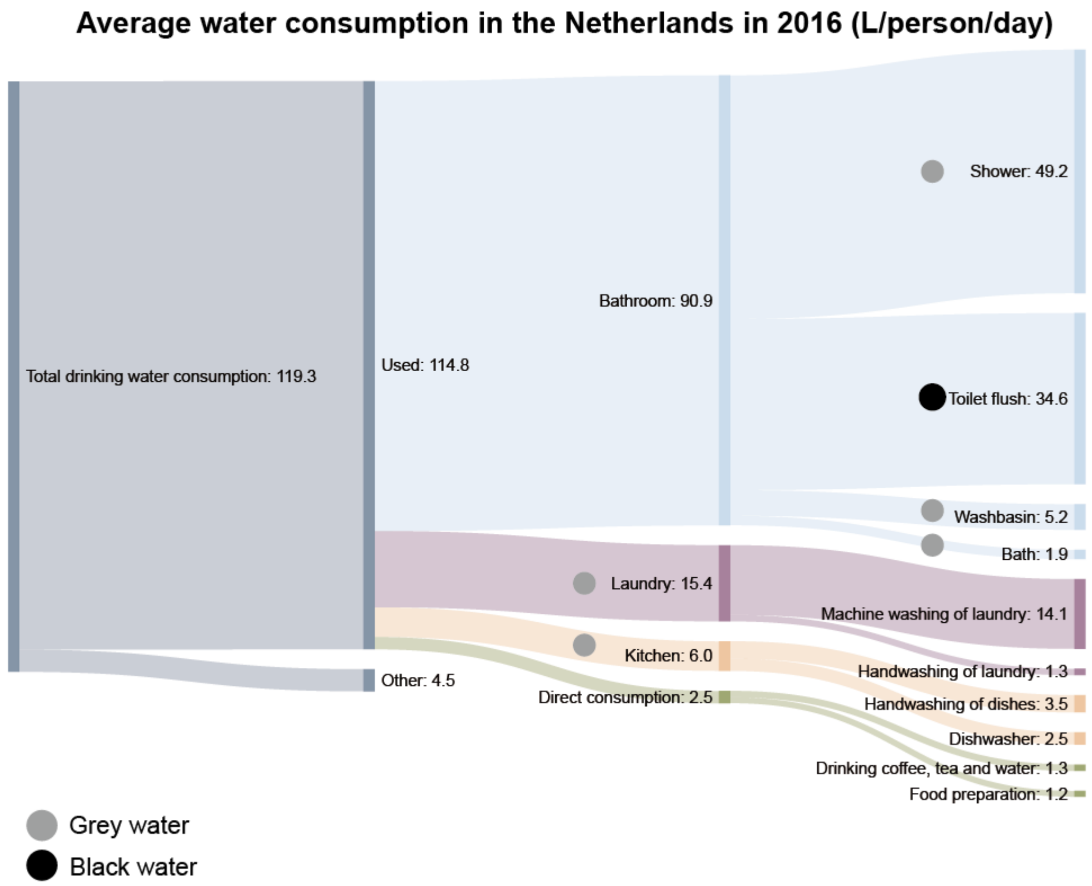


Figure 15. Drinking water use (L/day) in the Netherlands by application in 2016. Data from Vewin (2017)

The research (Vewin, 2017) also investigates the difference of the amount of water consumption and type of use by age, gender and size of the household in the Netherlands in 2016. Figure 16 shows that younger people use more water for showering, probably because they do more sports and take shower more frequently. It is also found that while the elderly (age 65+ years old) use the least water for showering, their water consumption for toilet flushing ranks the highest in all age groups. It may be because more frequent toilet visits and less installations of water-saving toilet among old houses. Gender and the size of household also have influence on the daily water consumption per person (Figure 17). Generally, men use an average of almost 10 litres of drinking water less per day than women. The biggest difference of water use between male and female appears in the amount of water used for toilet flushing (approximately 7 litre). This can be explained by frequent sanitary visit by women; and another possible reason is that the urinal toilet used by male users requires less flushing water than the common toilet. When looking at the household size and water use, people living in larger households use least water per person than those living in smaller households, which can be explained by the shared use of water facilities (e.g., washing machine) in large households.

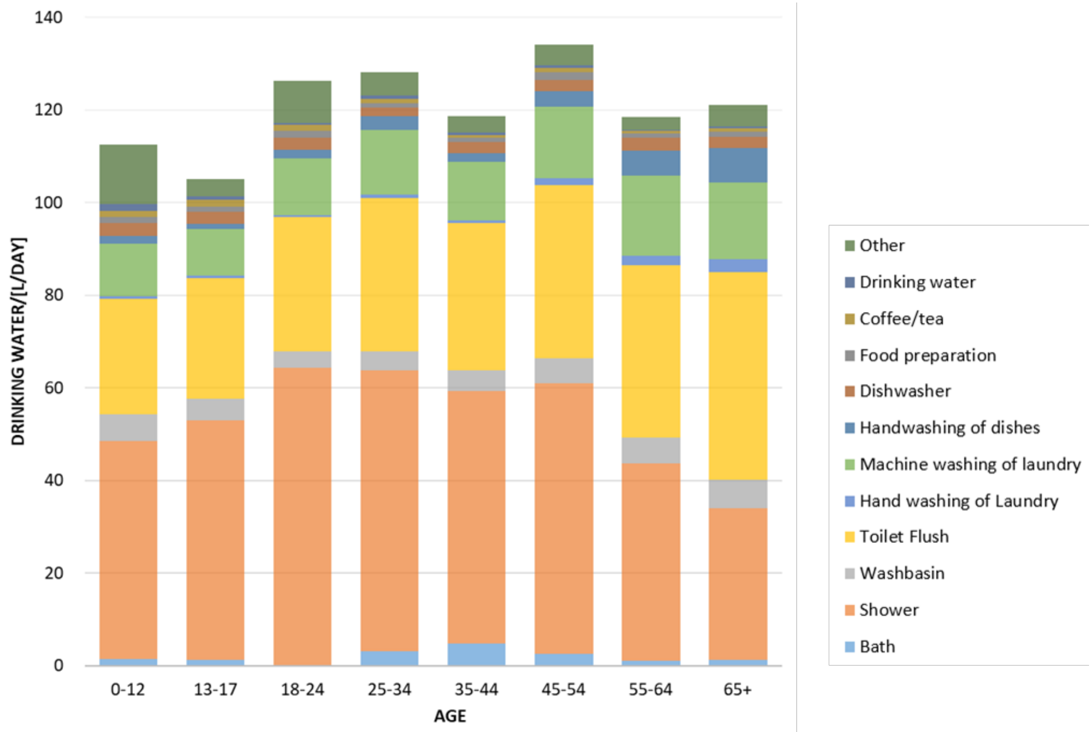


Figure 16. Water consumption by age in the Netherlands in 2016. Data from Vewin (2017)

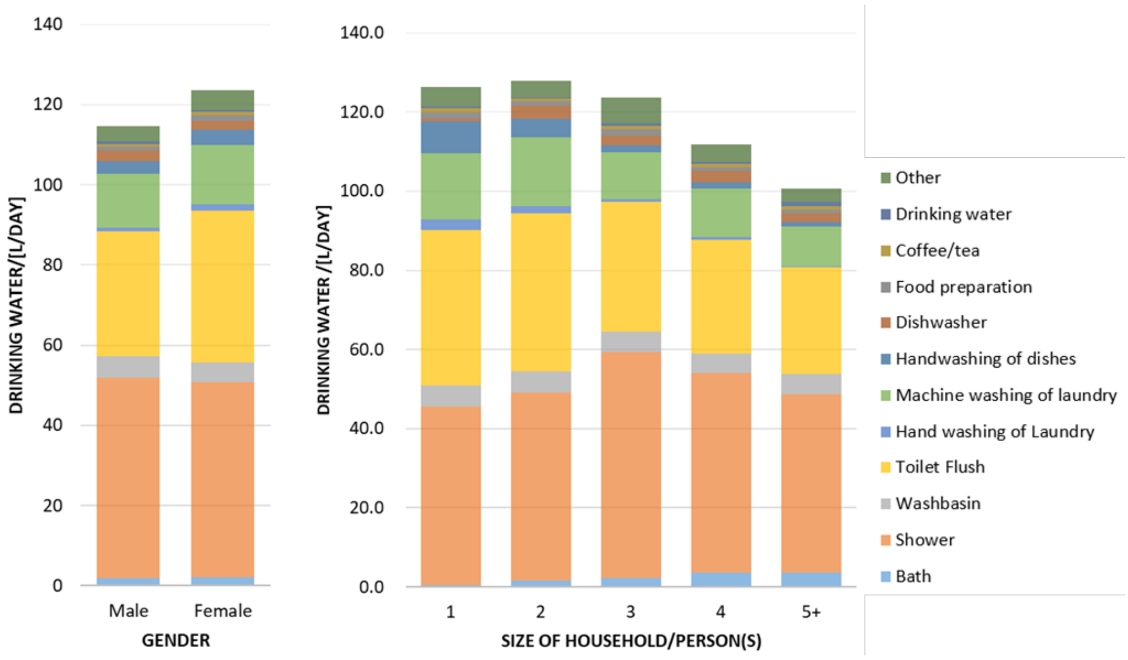


Figure 17. Water consumption by gender and size of household in the Netherlands in 2016. Adapted from Vewin (2017)

Another big water user at homes is the swimming pools that people put in their garden during summer season. For example, a pool of 2 by 3 meters and 1-meter high can hold 6000 litres of water, that is a lot of water compared to the average 119 litres of drinking water consumption per person per day. A spokesman of Brabant Water stated that on warm days the average drinking water consumption shoots up to 160 litres/person/day (BNDeStem, 2020). The spokesman believed that although there is no evidence to show where the extra water goes, the swimming pools certainly contribute to it.

In the summer of 2018, the drinking water company Brabant Water has called on their customers to voluntarily save drinking water. Brabant Water noticed that after the calls for economical use of drinking water, the consumption of drinking water was approximately 10% lower than expected (Leerdam, 2019). In terms of the willingness of making adjustments among Dutch citizens, the survey conducted by NOS in 2019 showed that more than 50% of the respondents indicated that they are willing to save drinking water by showering less (67%), washing their car less (59%) and spraying less water in the garden (50%), respectively (NOS, 2019).

4.2 Industrial water use

Industrial water requires a set of different quality standards depending on the purpose of water use. Water with drinking water quality is not always necessary in industrial applications. In the food and beverage sectors, water of superior quality is an important raw material. In order to extract water of good enough quality, these sectors in North Brabant wish to be able to extract groundwater from deeper depths (Verhagen, Stuurman, Van Steijn, & Hunink, 2017). In metal sector, the melting of metals requires a lot of cooling water. Regarding the chemistry sector, water is used during the production process (e.g. for cooling) and in the product itself (VEMW, 2013).

There are more than 50,000 addresses with business activities in North Brabant. The subsidiary company of Brabant Water – HydroBusiness supplies industrial water with different water sources, such as rainwater, surface water and groundwater. Some companies also have their own extraction points on site. By far the largest industrial consumers of groundwater in North Brabant are breweries (Bavaria and Heineken), galvanising (Budelco/Nyrstar), dairy (Campina) and chemistry (Fujifilm) companies (Verhagen, Van Steijn, Hunink, & Stuurman, 2017).

In recent decades, the amount of groundwater used by industrial sectors in Brabant has fallen sharply from around 100 million m^3/year in the mid-1970s to 20 million m^3/year in the recent years in North Brabant. Water has been used more efficiently by saving and/or reusing on the initiative of companies and under pressure from legislation and regulations. For large industrial customers, Brabant Water will provide advice on water savings and reuse based on a water scan which shows the water flows in the company.

4.3 Agricultural water use

Of the nearly 500,000 ha of land in North Brabant, about 232,000 ha is occupied by agriculture (46%) (Venema et al., 2020). The irrigation extractions are usually in the shallow groundwater layer. On average, the amount of agricultural groundwater extractions is small, but there are many extraction points in the province. The location and depth of the irrigation wells differs per region. Figure 18 shows that the average depth of irrigation extraction is generally deeper in the western area of North Brabant than that of other areas. This is because groundwater is available in the deeper soil layer in this area.

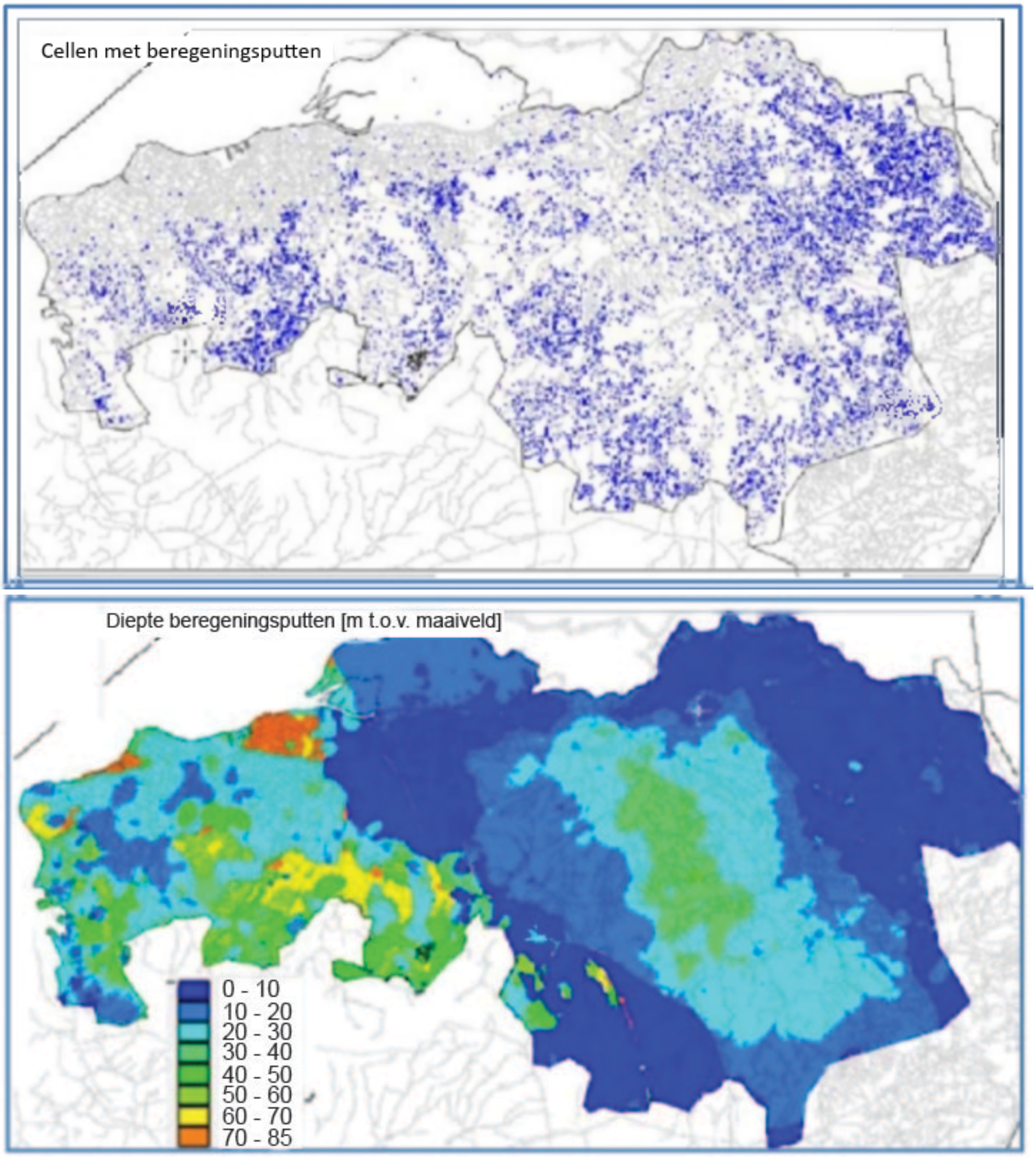


Figure 18. Locations of irrigation with groundwater (top) and the estimated depth of extraction (down)

In times of drought, crops are irrigated mostly with groundwater (80%), while the reminder irrigation water comes from surface water (Verhagen, Stuurman, et al., 2017). There are six types of agricultural land use with different water demands in North Brabant. Water demand by the six agricultural sectors varies greatly between wet and dry years (Table 2). The amount of agricultural irrigation will increase due to the following reasons (Verhagen, Van Steijn, et al., 2017):

1) More frequent irrigation due to greater rainfall shortages.
2) Climate change may change crop growth, which may also change the time of the water demand for irrigation.
3) Expansion of the irrigated area.

Table 2. Theoretical irrigation requirement of crops (Noord-Brabant, 2018)

Type of crop	Irrigation requitement (average year) *	Bandwidth wet-dry year**
Grassland	75mm	0-150mm
Silage maize	75mm	0-150mm
Arable farming	75mm	25-150mm
Open-field horticulture	75-100mm	25-175mm
Arboriculture	75mm	25-150mm
Greenhouse horticulture***	0mm	0-100mm

* An average year concerns 3 irrigation cycles of 25 mm of each cycle; ** No irrigation takes place in a wet year. In a dry year 6 watering of 25 mm each; *** Greenhouse horticulture only needs partial irrigation from groundwater in dry years. In wet and dry years, the water obtained from rainwater is sufficient.

4.4 Water requirements by nature

Naturally, all nature needs water. Especially for the plant species which grow abundantly on dry sandy soil (e.g., heath), the most important water source is the rainwater retained in the shallow soil layer. These groundwater-dependent nature types appear to be very vulnerable to drought when rainwater is less retained. In the research exploring nature water demand in Brabant, water demand by nature is divided into two categories (Deltares, 2020):

1) **Direct water demand**: the amount of groundwater that is required by groundwater-dependent nature to function properly.
2) **Spatial groundwater demand**: the amount of water needed to raise groundwater levels outside the natural boundaries. The groundwater level is also a determining factor for plant growth in nature reserves. Whether or not these plants can absorb enough water depends on groundwater levels in as well as outside the nature reserves. This is because plants have shallow roots so that they can only use the groundwater within their root zone. Only when the regional groundwater level reaches the root zone, the plants can absorb the water. Without enough spatial groundwater, groundwater levels in nature reserves would steadily decrease due to lower groundwater levels at their borders.

The direct water demand of nature in North Brabant is about 50-60 million m^3/year of groundwater; while an estimated of additional 350 million m^3/year of groundwater is needed to raise the groundwater levels structurally (Deltares, 2020). To make the additional 350 million m^3 groundwater available in North Brabant, 250 million m^3 of extra water should be kept per year in the region plus a decrease in groundwater extraction of approximately 100 million m^3/year (Deltares, 2020).

Figure 19 illustrates the current states and approaches to remedy the desiccation of groundwater-dependent nature. In the current situation, the groundwater level is too low to let the plants absorb enough water. In the agriculture sector much water is drained through ditches, while the excess rainwater flows away through surface water systems. In addition, a lot of groundwater is extracted by industry and drinking water companies. In the proposed situation, there will be fewer ditches in the agriculture field, leading to less drainage and more water retention. More surplus precipitation will infiltrate into the soil so that there will be more groundwater replenishment. The water demand by nature is also obtained from the significant reduction of groundwater extraction regarding irrigation, drinking water production and industrial water use. As a result, the groundwater level will increase regionally, and the nature reserves will have access to enough groundwater. This groundwater restoration is also good for other functions, such as agriculture, horticulture and urban infrastructure (e.g., reducing subsidence as a result of drought).

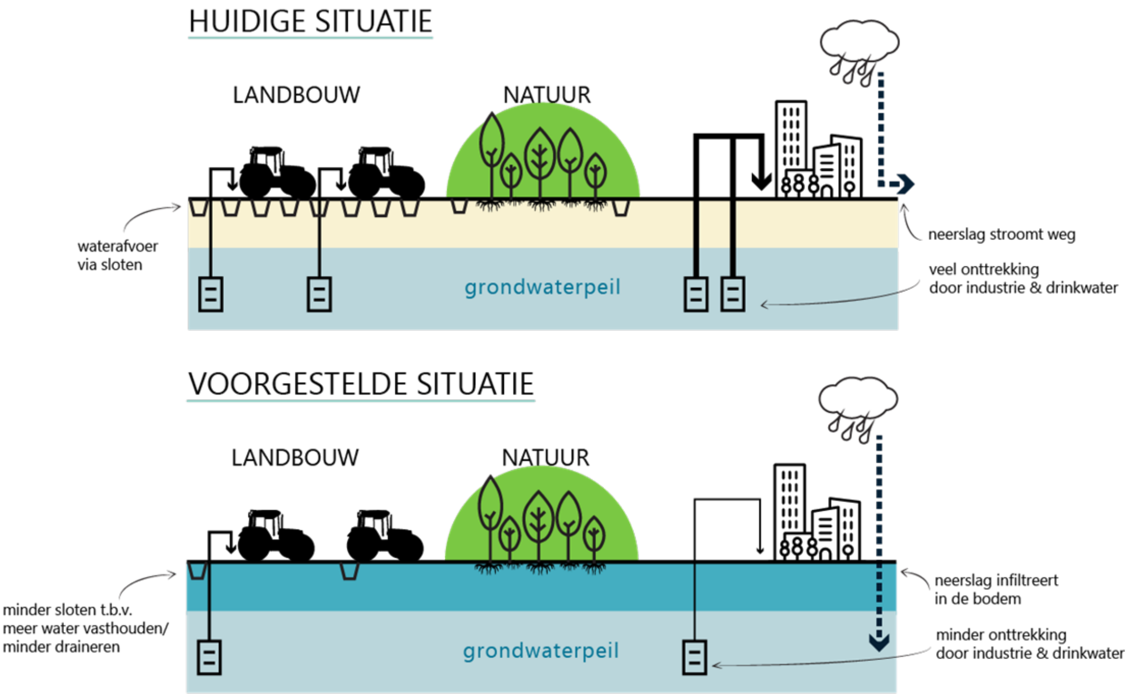


Figure 19. Illustration of the recovery of the water system (BrabantseMilieufederatie, 2020)

5 Conclusion

The main goal of this research was to determine whether there is a water abundance in the province of North Brabant in the long term and where the opportunities are for the creative industry to contribute to water abundance. When looking at the yearly available incoming water fluxes, there is sufficient water to sustain the current needs. However, the water demand and supply does not match over the year. In winter months when there is much rainfall, the groundwater level raises to high levels. Much of the surplus rainwater is drained via surface water rather than retained in the region. In summers months when there is much less rain, the agriculture sector needs to extract groundwater more often to irrigate the crops and the drinking water demand will increase as well. In addition, due to less rainfall in dry spring- and summer months, there will be less rainwater retained in shallow soil layers (less groundwater recharge), which leads to decreasing groundwater levels in summer. At the same time, groundwater is extensively used by households, industry and agriculture sectors. The current groundwater extraction per year has exceeded the yearly groundwater replenishment. On a yearly basis, there is no abundance in groundwater system in North Brabant, especially in dry years when agricultural sector can use up to twice of groundwater for irrigation compared to an average year.

Furthermore, there is no abundance of groundwater when taking into account the water demand by nature in North Brabant. For both drinking water production and irrigation groundwater is used, but these sectors extract groundwater from different depths, using different aquifers (Figure 10Figure 10. Groundwater extractions in the subsurface of North

Brabant. Working area of the Dommel is located in the 'Centrale Slenk'). While drinking water production is by far the largest groundwater user, these wells extract groundwater from deeper aquifer, which has less direct influence on the groundwater level at shallow aquifer. Although agriculture sector uses less groundwater throughout the year, their influence on nature can be significant due to extraction in shallow groundwater layers. Especially in dry years, large amount of groundwater is extracted from top aquifers for irrigation, which results in a groundwater level below the plant root zone so that plants cannot absorb enough water to grow.

6 Opportunities for creating water abundance

It is concluded that in the current situation, there is no water abundance in North Brabant, although there is enough incoming water in the region. Groundwater is the sole source for drinking water production and the main source for irrigation in North Brabant. In order to create water abundance, the groundwater situation should be improved on the one hand, and alternative water sources should be use in the applications when water with high-quality is not necessary on the other hand.

In summary, the groundwater situations in North Brabant can be improved in two ways:

1) Decrease in groundwater extraction

The amount of groundwater used by industrial customers is small compared to that of household and agricultural customers. Therefore, there is great potential in water savings at homes and agriculture sectors, leading to decreased groundwater extraction. The household consumers remain as the largest users of groundwater, while showering and toilet flush take up 70% of drinking water consumption at homes. On the other hand, groundwater demand for irrigation doubles in dry years. To achieve reduction in groundwater consumption, it is necessary to match the quality of water with the purpose of use in these two sectors.

2) Increase in groundwater replenishment

Water abundance can be created in North Brabant if proper amount of rainwater is retained in the region. The earlier groundwater carrying capacity study (Verhagen, Van Steijn, et al., 2017) shows that 80% the precipitation surplus is discharged via the drainage system, while only a small portion (around 12%) of this surplus reaches the deeper aquifers. To increase groundwater replenishment, the creative industry, policymakers and many other stakeholders can think of measures or facilities for rainwater retention and infiltration at households and public space.

Opportunities for creating water abundance in each sector are listed in below:

Households:

1) Circular use of water at home by matching the water quality with the purpose of use, such as disconnecting toilets from drinking water supply.
2) Collect rainwater at home and use it for activities requiring low-water quality, such as watering the garden, toilet flushing.

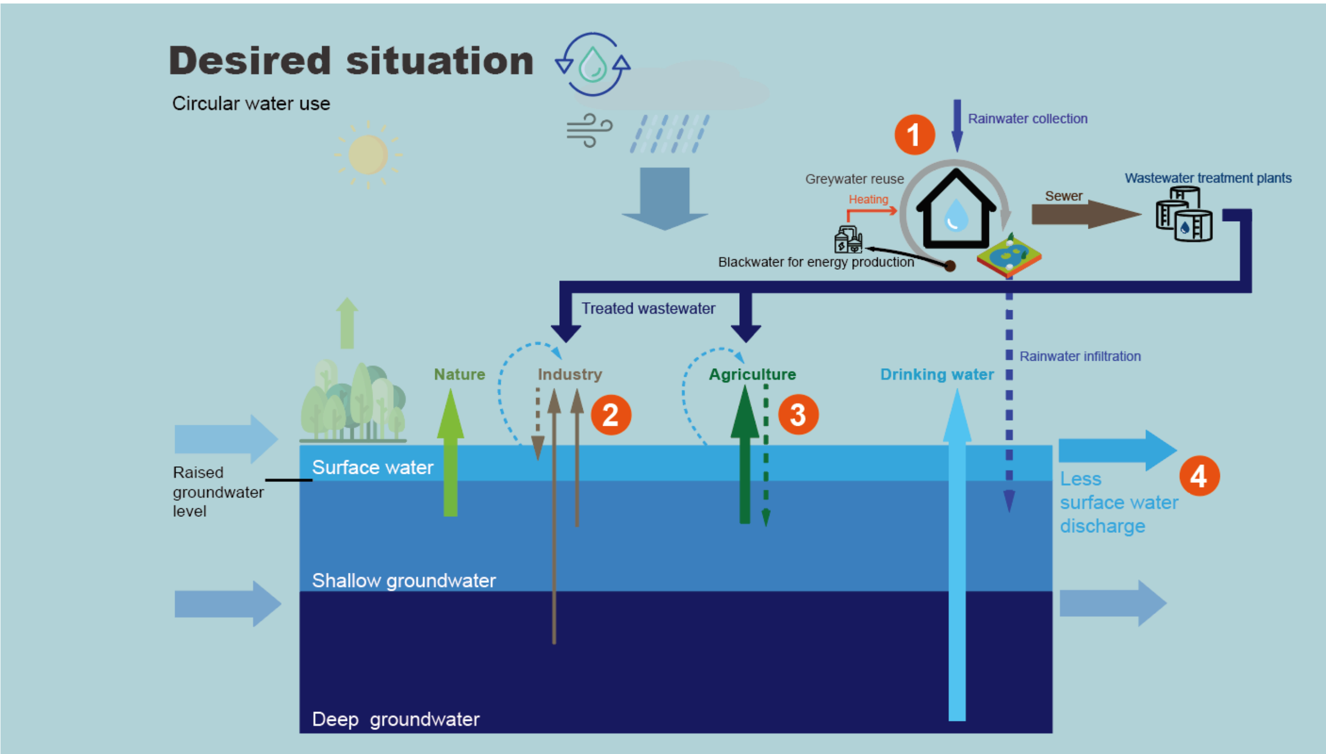
3) Reuse greywater, including water from shower, bath, laundry and sink, etc. Collect greywater (& rainwater) and have it treated at a local water treatment facility, then reuse the treated water for activities requiring low-water quality.
4) Create green areas and/or water ponds in gardens or public space to retain rainwater and enable water infiltration.

Industry:

1) Use surface water to replace groundwater in the industrial processes with low water quality requirements.
2) Use treated wastewater from near wastewater treatment plants/water factories.
3) Discharge excess clean industrial water back to surface water system.

Agriculture:

1) Replace part of groundwater with surface water for irrigation.
2) Use treated wastewater from near wastewater treatment plants/water factories.
3) Decrease the number of ditches, increase drainage levels, and create water ponds in fields to retain water.



Opportunities for creating water abundance

1

1. Wastewater separation; Greywater reuse locally, blackwater for enery production
2. Rainwater collection and use locally
3. Create water ponds and green areas to retain water and enable water infiltration

2

1. Use surface water to replace groundwater in the industrial processes with low water quality requirement
2. Use treated wastewater from near wastewater treatment plants/water factories.
3. Discharge excess clean industrial water back to surface water system

3

1. Replace part of groundwater with surface water for irrigation.
2. Use treated wastewater from near wastewater treatment plants/water factories.

4

1. Less ditches and higher drainage level in fields.
2. Create water ponds to retain water.
3. Increase green-paved area to enable rainwater infiltration

6.1 Best practices

In this chapter three demonstration projects are presented as inspiration for creating water abundance in household sector.

Waterschoon, Sneek, the Netherlands

In Sneek 232 new homes were connected to a decentralized sanitation and reuse (DeSaR) system. Wastewater comes from every household, plus the vegetable and fruit waste, are collected and treated in the treatment facilities in the neighborhood. In the utility building, wastewater is converted into biogas and other reusable substances. The converted biogas is then used for district heating system in the neighborhood. In particular, the treatment facilities are located in a utility building with the same size and style of a townhouse in the neighborhood (Figure 20). The house has a large window, so people can look inside and see the treatment facility. During the evaluation of this project, it was shown that the utility building help to create awareness among inhabitants, resulting in an additional 10% water savings (WaterSchoon, n.d.).

Figure 20. The utility building in Sneek (WaterSchoon, n.d.)

New sanitation, Amsterdam, the Netherlands

The idea of new sanitation is about the maximum recovery and local reuse of raw material and energy (Waternet, n.d.-b). Based on this concept, wastewater from household should be separated into blackwater stream and greywater stream. Thereafter, the traditional wastewater sewer is replaced by a multiple pipe system with vacuum pipe for blackwater collection and free-fall pipe for greywater. In this way, the raw material and energy can be converted as much as possible and reuse locally. The New Sanitation concept has been practiced in the Buiksloterham district in Amsterdam North. So far, the municipality has installed vacuum sewer system and 47 floating homes have been equipped with vacuum toilets (Waternet, n.d.-a).

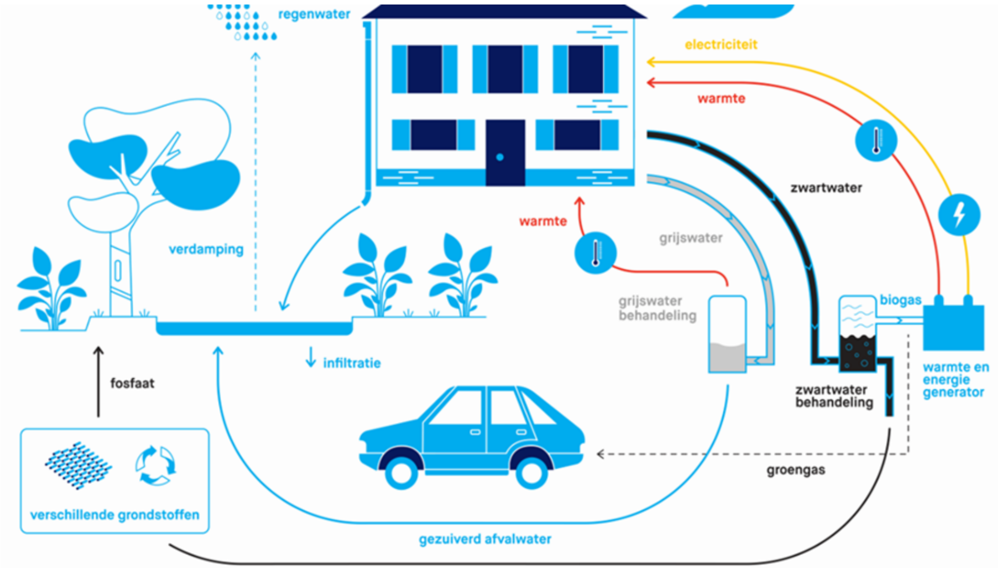


Figure 21. The principle of New Sanitation (Waternet, n.d.-b)

HAMBURG WATER CYCLE, Hamburg, Germany

The concept of the HAMBURG WATER CYCLE (HWC) provides a holistic approach to wastewater treatment and energy supply in urban areas. The most important feature of HWC is the separation of wastewater flows and the generation of energy from wastewater. Currently, the HWC concept is being implemented at two locations with different scales in Hamburg. One is a 9-hectare environmental adventure park in Gut Karlshöhe, which will be used as a demonstration system for the HWC concept. The other one is located in Hamburg-Jenfeld as part pf the 'Jebfelder Au' project. Built on around 35 hectares of a former barracks site, the residential building is expected to accommodate about 2000 new residents. These newly built houses will be connected to the HWC system, creating a district that enables climate-neutral living and sustainable drainage. In particular, rainwater retention area will be designed in open space in the district, which offers additional water storage potential in the event of heavy rain (Hamburg Wasser, 2020).

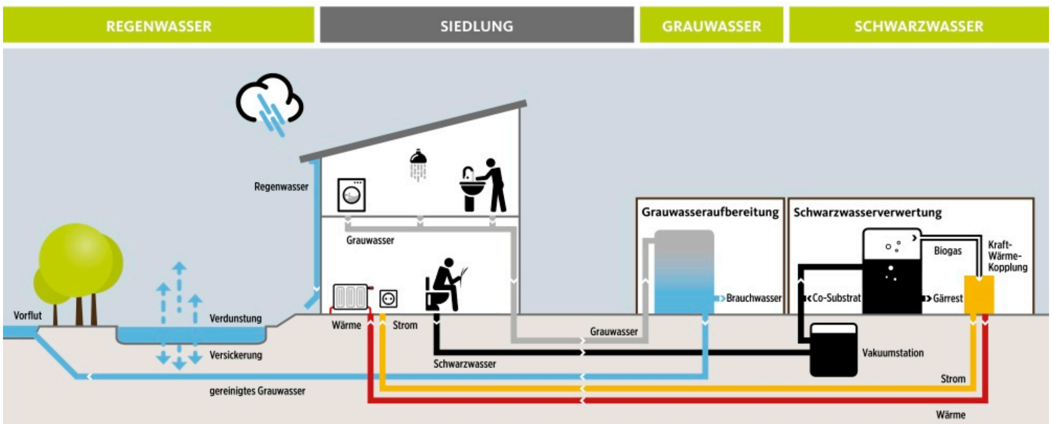


Figure 22. Concept of HAMBURG WATER CYCLE (Hamburg Wasser, 2020)

Appendix A. CLICKNL research presentation and workshop - 03-12-2020

Participants:

Waterschap De Dommel

- Joost van der Cruijsen
- Conny van Rooij

Brabant Water

- Sandra Verheijden
- Marleen Wickering

Gemeente Eindhoven

- Hans van Oosterwijk

Provincie Noord-Brabant

- Karla Niggebrugge
- Erik Kessels

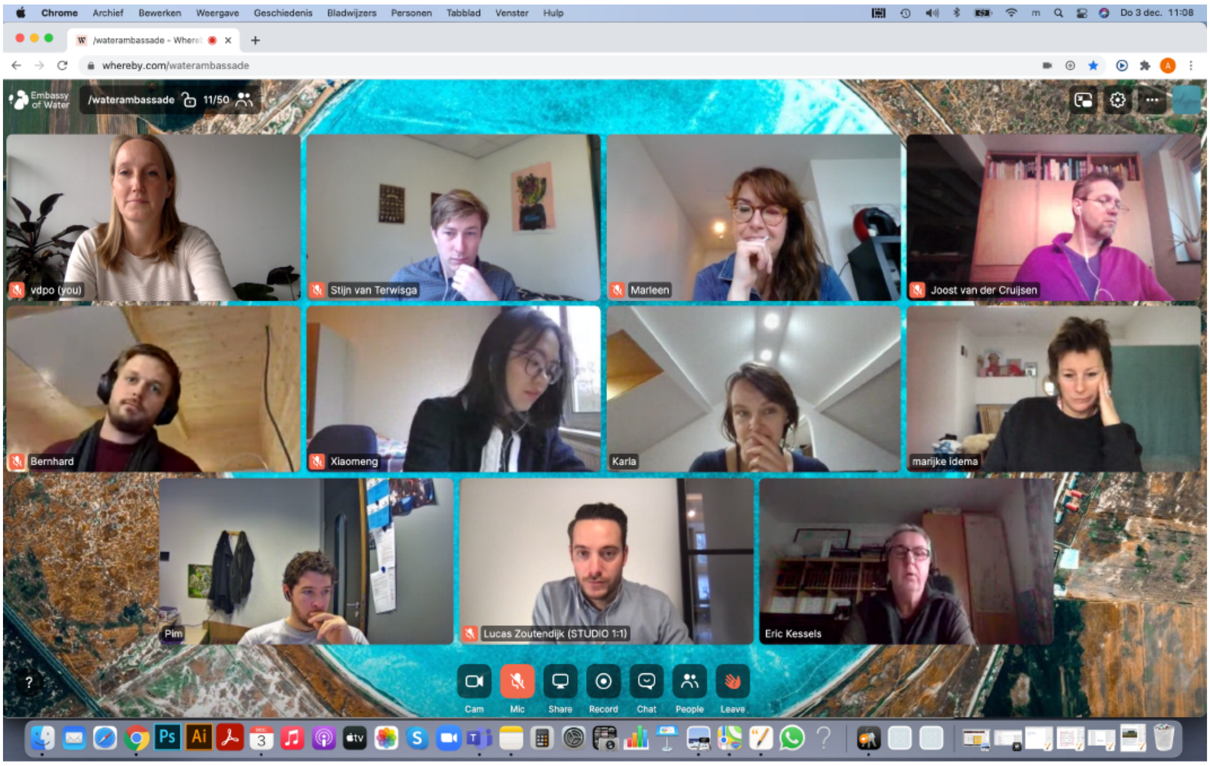
Design United

- Marijke Idema
- Pim de Jager
- Xiaomeng Zhou
- Stijn van Terwisga

Designers

- Bernhard Lenger (Studio Bernhard Lenger)
- Lucas Zoutendijk (Studio 1:1)

-



First Pim de Jager, Xiaomeng Zhou and Stijn van Terwisga presented their research inventory. After that we discussed it with the water professionals and designers. The collected research is all new to water professionals, but it is very nice to have this compact overview. It conveys the essence of the problem well. Very insightful.

The main response is: how can we put this in practice? How can we change the behavior of people, what is the Holy Grail?

Response from the designers: The example of the wastewater treatment plant in Sneek is very interesting. What is the reason for this 10% additional water saving? And how can we make this 10% bigger?
Can we add separate projects on social behavior besides the technical solutions?
If we make people part of the solution, by letting them help, would that increase this 10%?
What would the numbers say if you would introduce people into the system instead of merely being observer?

Transition from communicative installation to interactive installation. We used the case of a drinking water company applying for a drinking water permit next to a sensitive nature area as a concrete practical example in order to make the numbers and graphs from the research less abstract. We only had time for two of the three rounds, but we think this can be used very well for a follow-up discussion.

There were some comments added to some post-its and some ideas were also answers that fitted in round 3.

ROUND 1 What type of technical solutions do you expect can be implemented to improve the groundwater-level?

Top 3:

- Collect and treat rainwater/grey water at a central facility in a local neighborhood and reuse the treated water in that neighborhood
- Allowing more surfaces to be penetrable by water
- Create ponds in heide

ROUND 2: What are all the stakeholders that would be affected by the implemented measures?, and in what way would they be affected?

Top 3:

- People who "do well" can feel valuable /will be very pleased if they will somehow be 'rewarded' for their responsible water usage
- Farmers: investments and change habits
- Look for interesting stakeholders that will benefit from the downside of the measures

ROUND 3: Some of the stakeholders from round 2 will be affected in a negative way, or will be affected by the measure without understanding the purpose of them. How can we use creative/design/policy measures to increase their awareness/understanding and make the measures taken more effective?

- Note to round 1.1: Maybe there can be an event programming around that? Like cinemas, dinners, playgrounds. make a place that is usually seen as 'dirty' a fun place
- Note to round 2.1: Maybe if they have more a collective role instead of an individual one they can also see how they contribute to their neighbourhood e.g., the neighbourhood becomes greener and they can have direct influence on this. Through this the living quality or even the value of their property could increase
- Create technical solutions that somehow visualise or otherwise create awareness of the abundance (or a notification of shortage) the various qualities of water (black, grey, yellow, white?)
- People who "do well" can feel valuable /will be very pleased if they will somehow be 'rewarded' for their responsible water usage
- Communication / branding agency (Awareness and commitment)
- It shows the link between water behavior and the effect on nature.

Including people and stakeholders was seen as most important. In the past we did not need people to play a role in the water management system. Everything was taken care of. To involve them is new, so therefore a logical question: how do we do this? The water embassy puts forward the Confucius (or Benjamin Franklin) quote: “Tell me and I forget, teach me and I may remember, involve me and I learn.”

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