Irrigation demand change between 1954-1999 and 2050 for private allotments

Case study: Wageningse Eng

BSc thesis by Barbara Welling

June 2022

Soil Physics and Land Management Group

Irrigation demand changes between 1954-1999 and 2050 for private allotments

case study: Wageningse Eng

Bachelor thesis Soil Physics and Land Management Group submitted in partial fulfilment of the degree of Bachelor of Science in Soil, Water, Atmosphere at Wageningen University, the Netherlands

Study program:
Soil, Water, Atmosphere

Student registration number:
1041678

SGL80812

Supervisor:
Klaas Metselaar

Examinator:
First examinator: Klaas Metselaar
Second examinator: Jan Wesseling

Soil Physics and Land Management Group, Wageningen University

TABLE OF CONTENTS

List of figures

List of tables

1. ABSTRACT

Climate change will cause more drought periods, but how does that affect the water availability for urban gardening? And more specifically, private allotments at the Wageningse Eng. To investigate the changes in water in and outflows, a water balance is made. A rootzone depletion model is used to quantify the irrigation demand over 1954-1999. The rooting depth and irrigation amount are sensitive parameters that influence the results. A rooting depth of 80 cm and an irrigation amount of 0.5 mm (litre per square meter) are the best match with available data on current water usage by the allotments at the Wageningse Eng. Irrigation amount should be seen as an average irrigation amount over area. Irrigation is not distributed equally over this area, but rather focussed on as closely to the crops as possible. The irrigation amount applied per irrigation event is low, making the irrigation frequency high. Over the years 1954-1999 irrigation varies from 0.5 mm to 53 mm, with an average irrigation of 28.01 mm. This means that on average once every two to three days irrigation should be applied however, this also varies over the years.

The yearly irrigation over 46 years is also altered for the future in 2050, with yearly increase factors for precipitation and potential evapotranspiration. This is done for four different climate scenarios as described by the KNMI. For two of the four scenarios irrigation does not change, for the other two scenarios, linked to higher change in airflow patterns, the mean irrigation over 46 years increases on average to 29.47 mm and 29.60 mm. This is a first approximation and based on a multiplicative increase of rainfall and evapotranspiration, meaning that small rainfall events will also increase in size. Therefore, future irrigation is likely underestimated. On top of that, the used model and its values are only an approximation of the reality and several improvements must be made to the model to better quantify the water balance of the area.

2. INTRODUCTION

Urban agriculture, like allotments, can play a major role in relieving the world food demand, especially since more than half of the world population lives in cities as of 2007. Next to that urban agriculture brings the opportunity of improving the food supply, improves health conditions, supports local economies, improves social integration and environmental sustainability. Urban agriculture is thus good for humankind, but it is also good for the environment. It has ecological benefits: reducing city waste, improving biodiversity, improving air quality, reducing environmental impact that originates from food transport and storage. (Orsini, Kahane, Nono-Womdim, & Gianquinto, 2013). Irrigated agriculture will likely have to increase in the future to meet food demands for the growing population. However, it is unclear if sufficient water is available for this extension (Döll, 2022).

Periods of droughts have been occurring more often in the last years and will likely increase in Netherlands in the future (KNMI, 2021). This change in climate will also affect irrigation demands. Worldwide irrigation is expected to increase by 45% in 2080. However, irrigation efficiency will also increase by 20%, so an overall increase of 25% in irrigation water is predicted (Fischer, Tubiello, Velthuizen, & Wiberg, 2006). Pressurized irrigation systems and well thought out irrigation schedules can increase the water efficiency, which is the product yield per unit volume of water consumed by the crop. It can also reduce water losses through evapotranspiration and systems losses, compared to traditional irrigation (Nikolaou, Neocleous, Christou, Kitta, & Katsoulas, 2020).

Currently there is little scientific research available on how much water an allotment uses. In general more research has to be done on irrigation demands of small fields and allotments, especially on the changing demands due to climate change (Orsini, Kahane, Nono-Womdim, & Gianquinto, 2013) (Pratt, Allen, Rosenberg, Keller, & Kopp, 2019) (Döll, 2022) (Fischer, Tubiello, Velthuizen, & Wiberg, 2006). A survey by the National Allotment Society (England) found that it ranged from 0.48 to 176 Lm^{-2}, with an average of 21 Lm^{-2} (= 21 mm) per year (Ayling, Philips, & Ayling, 2021).

For a case study in Cache Valley in Utah, urban and small field were investigated. It was found that small fields had lower application uniformities and a greater irrigation depth than larger fields. It was also found that surface irrigation resulted in higher irrigation depths than sprinkle and drip irrigation. However, when a surface irrigation system is well managed it can outperform a poorly managed sprinkle system. Next to that, when using a fixed irrigation schedule a higher irrigation depth is present than when fields were irrigated inconsistently due to other facts (Pratt, Allen, Rosenberg, Keller, & Kopp, 2019).

Gardeners that are caring about the environment and sustainable water usage, do not necessarily use less water than people that think about it less. Gardeners that obey rules about water usage did use less water. This highlights the importance of enforcing rules and not just awareness about sustainable water usage (Egerer, Lin, & Philpott, 2018).

Wageningen has allotments at the Wageningse Eng, near Dolderstraat and the Diedenweg (figure 11). Some of the gardeners from the allotments use groundwater to irrigate their crops. Other gardeners use tap water, which originates from the Wageningseberg (Vitens, n.d.). They irrigate their crops using a watering hose or watering can. A water balance will quantify the water demand and supply in the Wageningse Eng area. A water balance is the most efficient and accurate way to quantify water fluxes in an area.

2.1 Research Question

The goal of this research is to assess the irrigation demand over 1954-2000 and compare this to the irrigation demand of 2050. The main research question is therefore: **How will the irrigation demand change in 2050 for the four climate scenarios G_L, G_H, W_L, and W_H that were considered by KNMI compared to 1954-1999?**

This will be answered using the following sub questions:

1. What is the water balance for the allotments at the Wageningse Eng?
2. What is the irrigation demand for the years 1954-2000?
3. What will the irrigation demand be for 2050 according to the four different climate scenarios?

3. MATERIALS & METHODS

3.1 Foundation Wageningse Eng

The allotments are part of the *Wageningse Eng Foundation*. The foundation strives to preserve and where possible enhance the natural, landscape and cultural-historical values of the Eng. The foundation specifically strives for an open landscape, restricting the development of a large rainwater collection structure (Stichting Wageningse Eng, 2022). On the other hand, they want all practices at the Wageningse Eng to be as sustainable as possible, also the water usage. Therefore, the foundation is interested in the usage of groundwater. The foundation also requested research by the Science Shop on the entire Wageningse Eng. In agreement with the Science Shop this thesis focusses on the allotments, rather than all the stakeholders at the Wageningse Eng.

3.2 Site description

The allotments researched for this thesis are located at the Wageningse Eng. At this site the soil is a **loopodzol**, which is a coarse sandy soil (pdok, n.d.). The loopodzol is not particular suitable for agriculture, therefore individual allotment owners alter the soil by adding organic matter, to increase the water retention capacity (Bakker, van der Lubbe, & Savenije, 2021). Each individual gardener has his own management practices therefore, organic matter content is expected to vary. In addition, most gardeners add mulches to the topsoil, (Bakker, van der Lubbe, & Savenije, 2021), to decrease the soil evaporation (Adams, 1966). The gardeners also consider crops that use less water, although it is not specified which crops those are (Bakker, van der Lubbe, & Savenije, 2021). The allotments have a great variety of crops and soil characteristics; therefore, assumptions need to be made. For this research the allotments are considered flat (see appendix Figure 12) (AHN, n.d.). The total area of the allotments is 13650 m^2 (van der Lubbe, 2022). The highest mean groundwater level (GHG) is deeper than 250 cm (pdok, n.d.). Vegetation will not be able to reach this groundwater during the entire year. Capillary rise is therefore excluded from the model as the system is dependent on precipitation and irrigation.

Water usage data is already available for three areas. From 2015 until 2021 tap water is used by the gardeners, which results in registration of the used water. The first two areas are near the Dolderstraat and have a surface area of 9880 m^2 (registry number C2374, C345, C341). The third area is situated near the Diedenweg and has a surface of 3670 m^2 (land registry number E4076). Figure 1 shows the registered water use for the two areas (van der Lubbe, 2022). The average over these areas and seven years is 26.73 mm. The variation between plots is however unknown. In 2020 there was a leakage at the Dolderstraat, causing higher water usage. At the Diedenweg there was no leak in 2020.

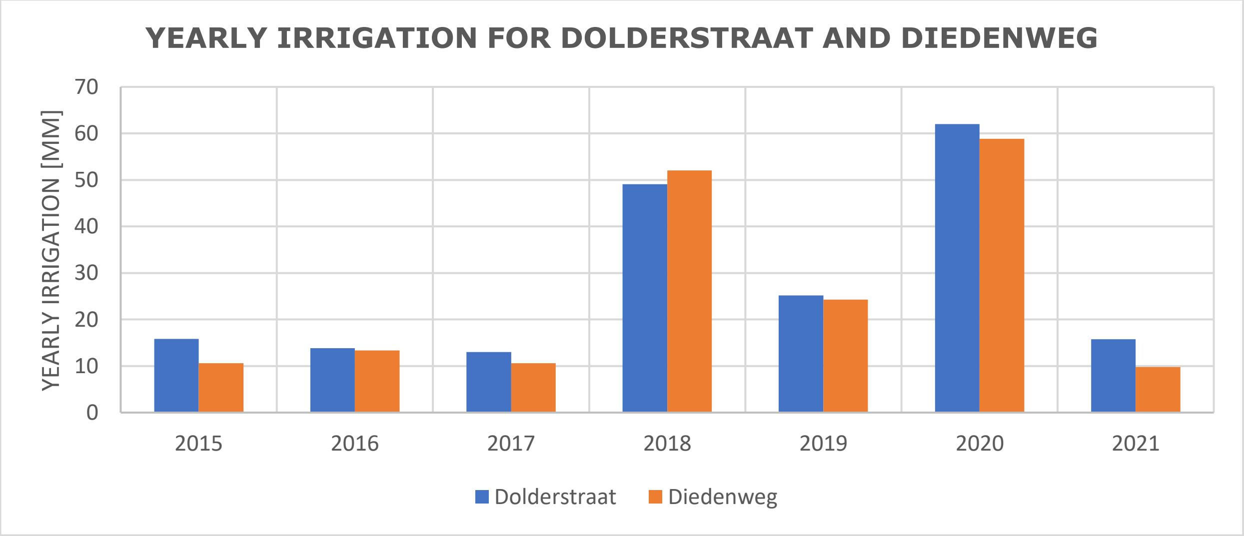

Figure 1: Yearly irrigation in mm for the allotment complexes of Dolderstraat and Diedenweg.

Yearly the irrigation varies from 9.81 mm to 58.9 mm (or 62.02 mm for Dolderstraat in 2020). Each allotment has other gardeners, which explains the spatial difference. When comparing 2015 to 2016, the water usage of Dolderstraat decreases, while the water usage by Diedenweg increases. The average of these three areas over five years is 26.73 mm. The foundation Wageningse Eng also reported that as of 2022 one pumping station is situated at the allotments at 28 meters depth. This pump can extract around 600 m^3 water per year (Bakker, van der Lubbe, & Savenije, 2021).

3.3 Water balance

To quantify the water for the allotments a water balance is made using Microsoft Excel. The following in and outflows will be used: precipitation, irrigation, evapotranspiration, soil storage and deep percolation. This is also illustrated in figure 2. The water balance is based on the rootzone depletion approach by the FAO Irrigation and Drainage Paper No. 56 (Allen, Pereira, Raes, & Smith, 2006). Next to irrigation the concepts used in the model are total available water, readily available water, rootzone depletion, precipitation, evapotranspiration, and deep percolation. In chapter 3.3.1-3.3.8 the water balance is discussed in more details.

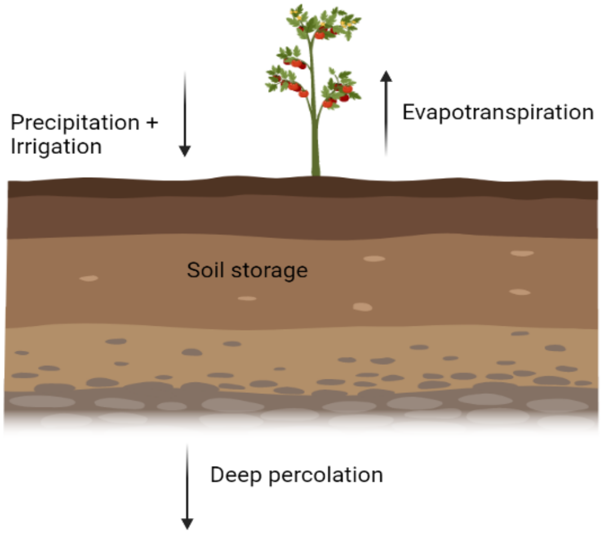

Figure 2: Schematic representation of the water fluxes of the water balance model. Inflow fluxes are precipitation and irrigation. Outflow fluxes are evapotranspiration and deep percolation. Water can also be stored in the soil as soil storage.

3.3.1 Total available water

When a precipitation event occurs, the soil is wetted and will then be drained until field capacity is reached (Nachabe, 1998). Field capacity is defined differently by hydrologist (Minasny & McBratney, 2018). For example, for field capacity usually a range in 1/10 to 1/3 bar for the matrix potential of the soil moisture (Cornell University, 2010). The definition used in this bachelor thesis: the amount of water that a well-drained soil can hold against the gravitational forces, or the amount of water that remains in the soil when downward drainage has markedly decreased (Allen, Pereira, Raes, & Smith, 2006). Water is taken up by plants, which causes the other water particles to be held against soil particles with greater force. Therefore, when the water content in the soil decreases, it becomes more difficult for plants to extract that water. At a certain moment there is so little water in the soil that no more water can be extracted. This is the wilting point. The total available water (TAW) in the rootzone is defined as the difference between the water content at field capacity and at wilting point (Allen, Pereira, Raes, & Smith, 2006). The formula to calculate TAW (in cm) is therefore:

$$TAW = (\theta_{FC} - \theta_{WP}) * Z_r \qquad (1)$$

Where:

- Z_r is the rooting depth of the crops in cm, discussed in 3.4. optimization procedure
- Θ_{FC} is the soil moisture content at field capacity in cm^3cm^{-3}, with a value of 0.19 (Allen, Pereira, Raes, & Smith, 2006)
- Θ_{WP} is the soil moisture content at wilting point in cm^3cm^{-3}, with a value of 0.07 (Allen, Pereira, Raes, & Smith, 2006)

The rooting depth is dependent on many factors and is a study by itself. Therefore, an optimization procedure will be performed to determine the best suitable rooting depth. For different rooting depths, the yearly irrigation is compared to available data shown in figure 1.

The soil moisture contents are soil type specific, for this research a homogeneous soil type of loamy sand is chosen. The difference between field capacity and wilting point ($\theta_{FC} - \theta_{WP}$) range within 0.06-0.12. For this research the difference is chosen to be 0.12. The calculated TAW value is therefore 9.6 cm.

3.3.2 Readily available water

As mentioned before, crop water uptake is reduced when the amount of water in the soil decreases. When the soil water content is below the readily available water (RAW in cm) point, water cannot be transported fast enough to the roots and the crop will experience drought stress. Thus, only a fraction of the TAW can be extracted from the root zone. This can be calculated with the following formula:

$$RAW = p * TAW \qquad (2)$$

Where:

- p is the depletion fraction, which is dependent on crop type and evapotranspiration

Standard depletion fraction values per crop type are available, but they can also be calculated for more reliable values (Allen, Pereira, Raes, & Smith, 2006). This is done through the following formula:

$$p = p_{table\ 22\ FAO\ 56} + 0.04 * (5 - ET_c) \qquad (3)$$

Where:

- $p_{table\ 22\ FAO\ 56}$ is the standard depletion fraction, with a value of 0.4 for tomato (Allen, Pereira, Raes, & Smith, 2006)
- ET_c is the specific evapotranspiration in cm/day

The crop evapotranspiration, depletion fraction and readily available water are time dependent and vary per day.

3.3.3 Rootzone depletion

To determine when irrigation should occur, the rootzone depletion model is used. The rootzone depletion (Dr) is calculated as follows:

$$D_{r,i} = D_{r,i-1} - P_i - I_i + ET_{c,i} + DP_i \qquad (4)$$

Where:

- P is precipitation in cm/day
- I is irrigation amount in cm/day
- ET_c is the crop evapotranspiration in cm/day
- DP is the deep percolation in cm/day

The subscript i refers to the day, so i-1 equals yesterday.

When no precipitation occurs, the amount of water in the soil decreases over time. This increases the rootzone depletion. In case precipitation occurs, the soil moisture amount increases and the rootzone depletion decreases again. This can be seen as the vertical blue line with a cloud and the letter P above it. When the rootzone depletion exceeds the readily available water (Dr ≥ RAW), irrigation should occur. In figure 3 this can be seen as the vertical line with a watering can and the letter I above it. In case a precipitation event happens and the rootzone depletion becomes negative, the water cannot be stored in the soil, and it will be percolated to the groundwater, indicated by DP. A time-step before the first data the rootzone depletion is set to zero.

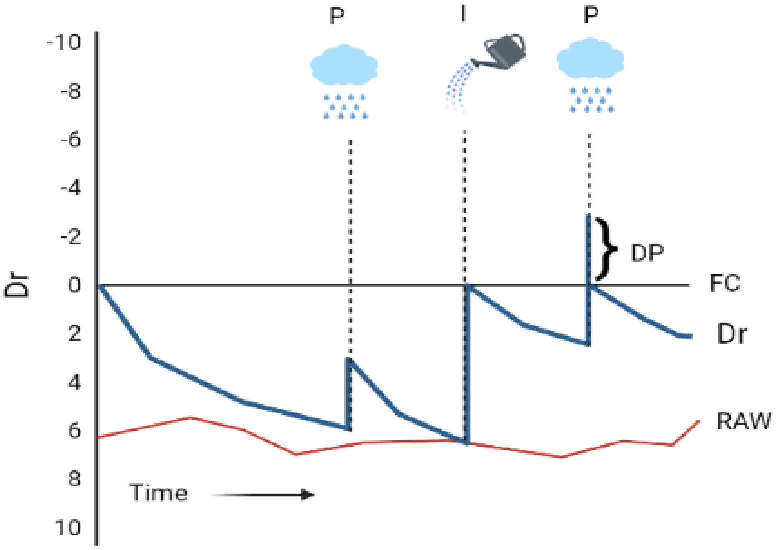

Figure 3: Schematic visualization of the rootzone depletion model over time. Dr is the rootzone depletion, P is the precipitation, I is the irrigation, DP is the deep percolation, FC is the field capacity, RAW is the readily available water. As time passes on x-axis, Dr and RAW change.

3.3.4 Precipitation

The precipitation data is acquired from the Haarweg weather station. Since the station was moved in 2000 the data is available from 1-1-1954 until 31-12-2000. Meteorological data from 2001-2021 is available for the Veenkampen weather station but is not considered for this research, due to time restrictions. The data is provided by the meteorology and air quality group of the Wageningen University and Research. The year 2000 had high yearly precipitation: 1473.5 mm. Also, yearly precipitation events were as high as 140 mm rain on one day. It was therefore decided to leave the meteorological data of 2000 out of the research and focus on meteorological data from 1-1-1954 until 31-12-1999.

3.3.5 Irrigation

Irrigation is incorporated into the model to prevent water stress and optimize crop growth. As mentioned above, when D_r ≥ RAW irrigation is applied. The irrigation amount is the amount of irrigation that is applied per irrigation event, which is once per day if necessary. Its value is based on an optimization procedure. Outside the growing season of the tomatoes the irrigation is set to a default value of zero. The irrigation amount is in litres per square meter (mm), but irrigation will not be distributed equally over the area. Gardeners apply irrigation as close to the plants as possible, causing irrigation to be higher near crops and lower or zero further from crops. From now on mm and lm^{-2} are used interchangeable. In reality gardeners will apply irregularly and therefore irrigation amount should be seen as an average irrigation amount over area.

3.3.6 Evapotranspiration

Potential evapotranspiration (ET_{pot}) is also acquired by the meteorology and air quality group of the Wageningen University and Research, at the weather station of Haarweg. ET_{pot} is multiplied with the crop coefficient, K_c, to obtain the crop evapotranspiration:

$$ET_c = K_c * ET_p \qquad (5)$$

The crop chosen for this research is tomato as one crop had to serve as an example and many gardeners grow tomatoes. The crop coefficient is a changing factor during the growing season and is specific for each crop type. The growing season is divided into four phases: initial phase, development phase, mid phase, and end phase. The initial and mid phase have a constant K_c value, while the development and end phase have a linear relation, this is also shown schematically in figure 4. This transition of crop coefficient between stages occurs more fluently in reality (Allen, Pereira, Raes, & Smith, 2006). Therefore, a simple estimation is made based on literature (Allen, Pereira, Raes, & Smith, 2006). In the model this is implemented by using a simple formula per day. For the development phase the following formula is used:

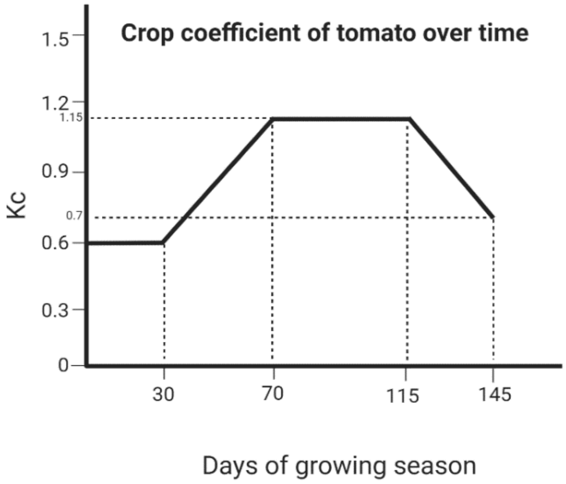

Figure 4: Crop coefficient for the four growing phases: initial phase, development phase, mid-phase, and end-phase.

$$K_{c,dev\ phase} = 0.6 + 0.01375 * n \qquad (6)$$

And for the end phase the following formula is used:

$$K_{c,end\ phase} = 1.15 - 0.015 * n \qquad (7)$$

Where:

- n is the number of days in that specific phase

Outside of the growing season K_c is set to 0.6, the value of the initial phase. In table 1 the length of each growing stage can be found. Yearly ET_C values for tomatoes range from 300-600 mm (Allen, Pereira, Raes, & Smith, 2006). Using the above-mentioned crop coefficient results in yearly ET_C within the range of 364-571 mm.

Table 1: Length and total of growing stages of tomato in days (Allen, Pereira, Raes, & Smith, 2006)

Stage	Length
Initial phase	30 days
Development phase	40 days
Mid-phase	45 days
End-phase	30 days
Total	145 days

For tomato a constant growing season is taken. Due to climate change the growing season is set to begin earlier and go on longer (KNMI, 2018). The growing season used for this research starts on April 1st and has the length listed below in table 2. Of the water used by an irrigated crop, only 0.01% of water is used by crops, the other 99.99% is evaporated (Schwalbe, n.d.). Water used by a crop is therefore ignored in the model.

This method for determining the crop coefficient can also be done for different crop types, using the same method. An allotment typically has a large variety of crops in a small space. Due to time issues the water balance model is only applied for tomatoes. In case more crop variety is represented, percentages need to be used. For example: 50% of the allotment is tomatoes, 30% carrots, and 20% lettuce. The water balance can be executed three times (number of different crops) and the irrigation amount should then be multiplied by the respective area to obtain the total amount of irrigation.

3.3.7 Deep percolation

Deep percolation occurs when the rootzone depletion becomes negative, which is also shown in figure 3 by DP. This means field capacity is reached and the soil cannot hold onto more moisture anymore. The following formula is used to calculate the deep percolation (DP):

$$DP_i = P_i + I_i - ET_{c,i} - D_{r,i-1} \qquad (8)$$

With the condition that $DP_i \geq 0$. The other parameters are explained above.

3.3.8 Implementation

In Microsoft Excel the precipitation and potential evapotranspiration data are added. Next, the formulas 1 up and including formula 8 are put in. Calculation over 46 years takes place: for each day the formulas are automatically executed, and the results are used for the calculation of the next day. Per year the total irrigation is summed, to simplify comparison with available data. The yearly irrigation is divided by the irrigation amount to obtain the total number of days irrigation should occur. The growing season is then divided by the number of days irrigation should occur, to obtain the irrigation frequency.

3.4 Optimization procedure

The rooting depth and irrigation amount are determined by a optimization procedure. Rooting depth is dependent on many factors. A compact soil will for instance limit root growth (Tracy, et al., 2012). Crops that root deeper can extract larger volumes of water from the soil (Fulton, 1970). During the growing season the roots grow deeper and the volume of water available to the plants increases as well. The irrigation frequency should then most likely be decreased (Fulton, 1970).

Per rooting depth in cm, the yearly irrigation is calculated in mm. This can be seen in figure 5.

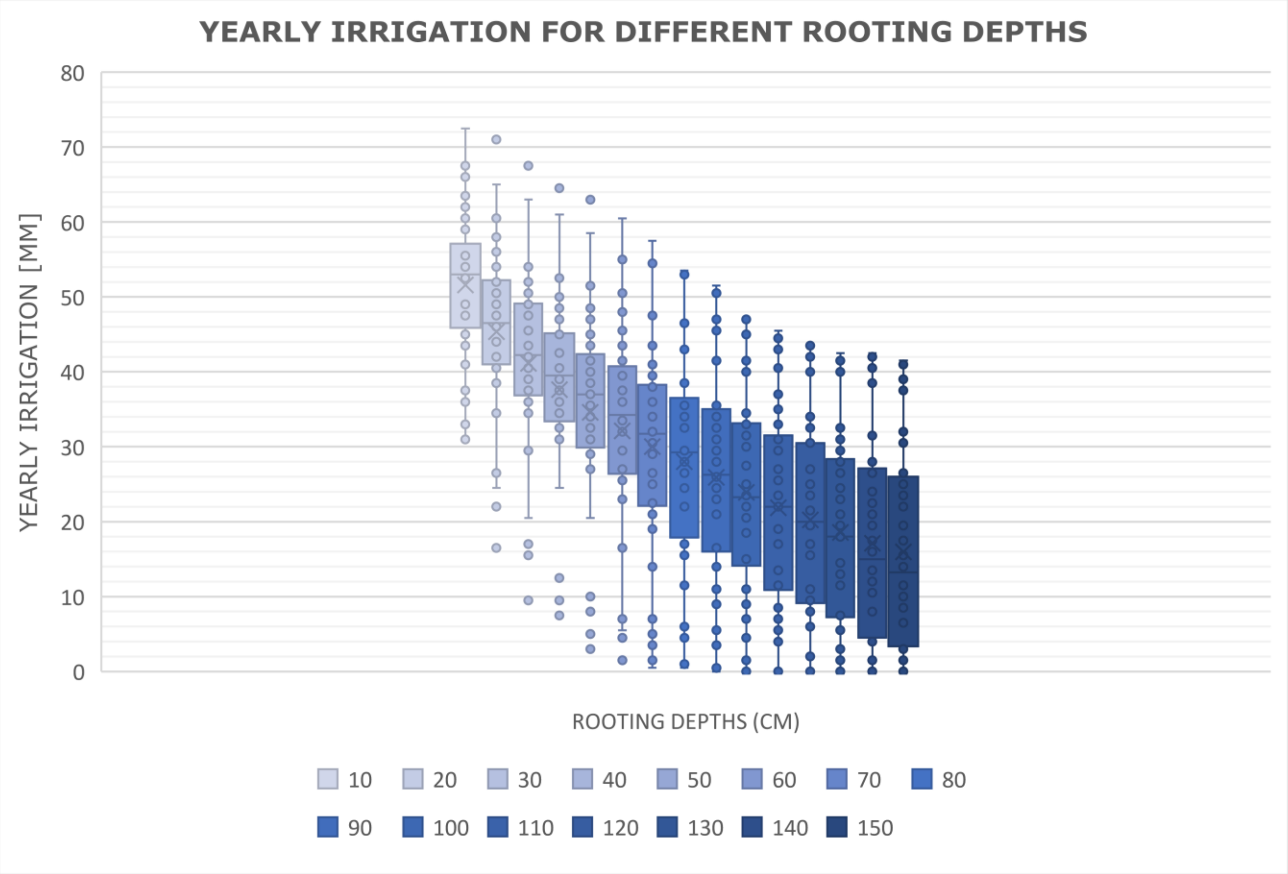

Figure 5: Scatter for yearly irrigation in mm, for different rooting depths in cm. The total yearly irrigation for 46 years is illustrated by dots per irrigation amount. Irrigation amount of 0.5 mm is used. Unfortunately, it was not possible to get the rooting depths on the x-axis, therefore the legend is situated below the x-axis.

The boxplot above shows multiple statistical values. The middle line in the box is the median, the top of the box is the 75th percentile, the bottom of the box is the 25th percentile. The line above the box is the maximum, which is calculated as the 75th percentile + 1.5 * interquartile range. The interquartile range is the 'distance' between the 25th and the 75th percentile. The line below the 25th percentile is the minimum, calculated as the 25th percentile – 1.5 * interquartile range. The dots above and below the maximum and minimum are outliers.

With increasing rooting depth, the total yearly irrigation decreases. For rooting depths up and until 80 centimeters the computed irrigation shows a normal distribution. From 80 centimeters onwards it seems more like a lognormal distribution. When the rooting depth is larger than 80 cm there are years in which no irrigation is required. For rooting depth of 30 and 40 cm the variability in irrigation is small between the years.

Based on this optimization procedure a rooting depth of 80 cm is chosen, as the mean (28.01 mm) matches with the available data explained in the introduction (figure 1).

The yearly irrigation is higher when the irrigation amount is higher, as can be seen in figure 6. The variability increases with increasing irrigation amount. An irrigation amount of 0.5 mm is chosen for the rest of the model, as the mean (28.01 mm) best matches with the available data explained in the introduction (figure 1).

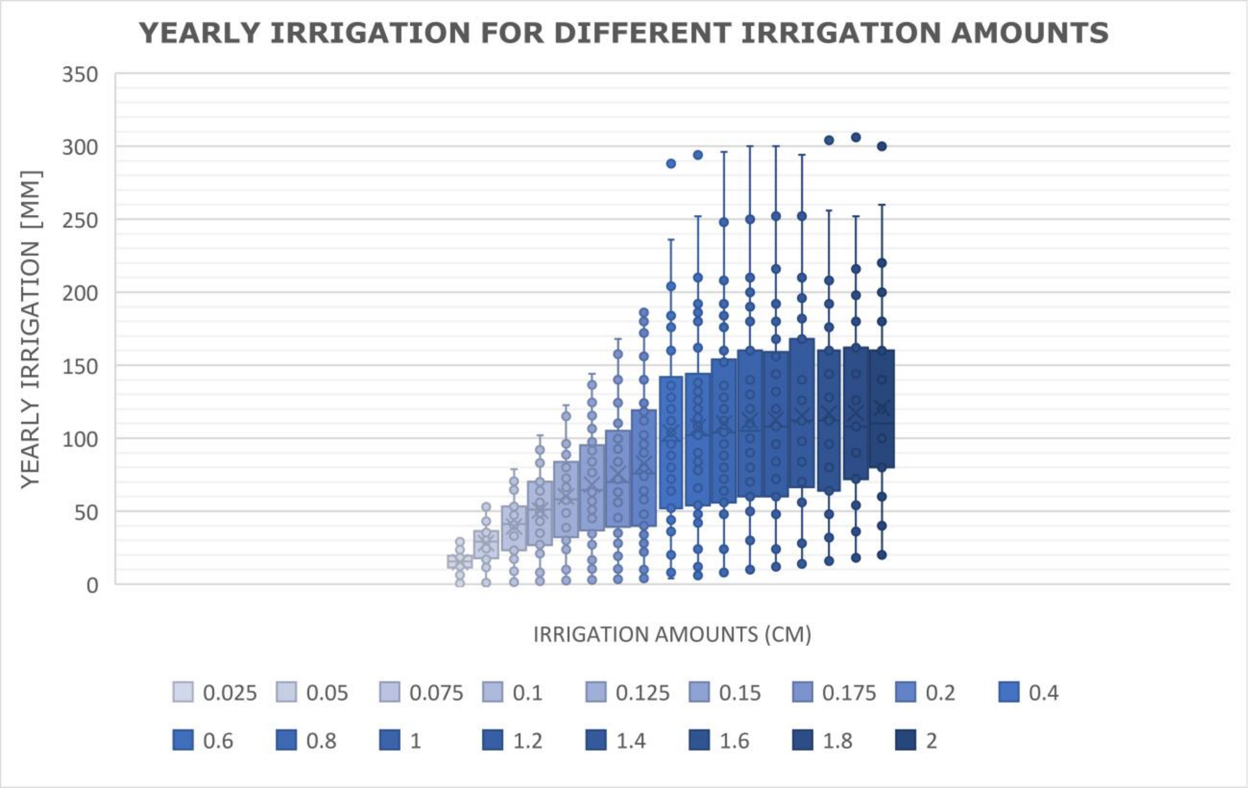

Figure 6: Scatter in yearly irrigation in mm, for different amounts of irrigation in cm. The total yearly irrigation for 46 years is illustrated by dots per irrigation amount. Rooting depth of 80 cm is used. Unfortunately, it was not possible to get the irrigation amounts on the x-axis, therefore the legend is situated below the x-axis.

It is important to note that the irrigation amount is the amount of water that is irrigated per irrigation event, while total irrigation is determined over an entire year. Per day it is determined whether irrigation is necessary, as explained in the methods.

When too much irrigation is applied, water will flow to the groundwater through deep percolation. With the help of an optimization procedure, it is illustrated in figure 7 how effective the irrigation is.

With an increasing irrigation amount, the deep percolation also increases. The variability between years does not vary significantly. Each irrigation amount has one outlier to the top, which is 1966 for each irrigation amount. In this year precipitation was very high. With the chosen 0.05 cm irrigation amount the deep percolation is rather small, which indicates that little water is lost.

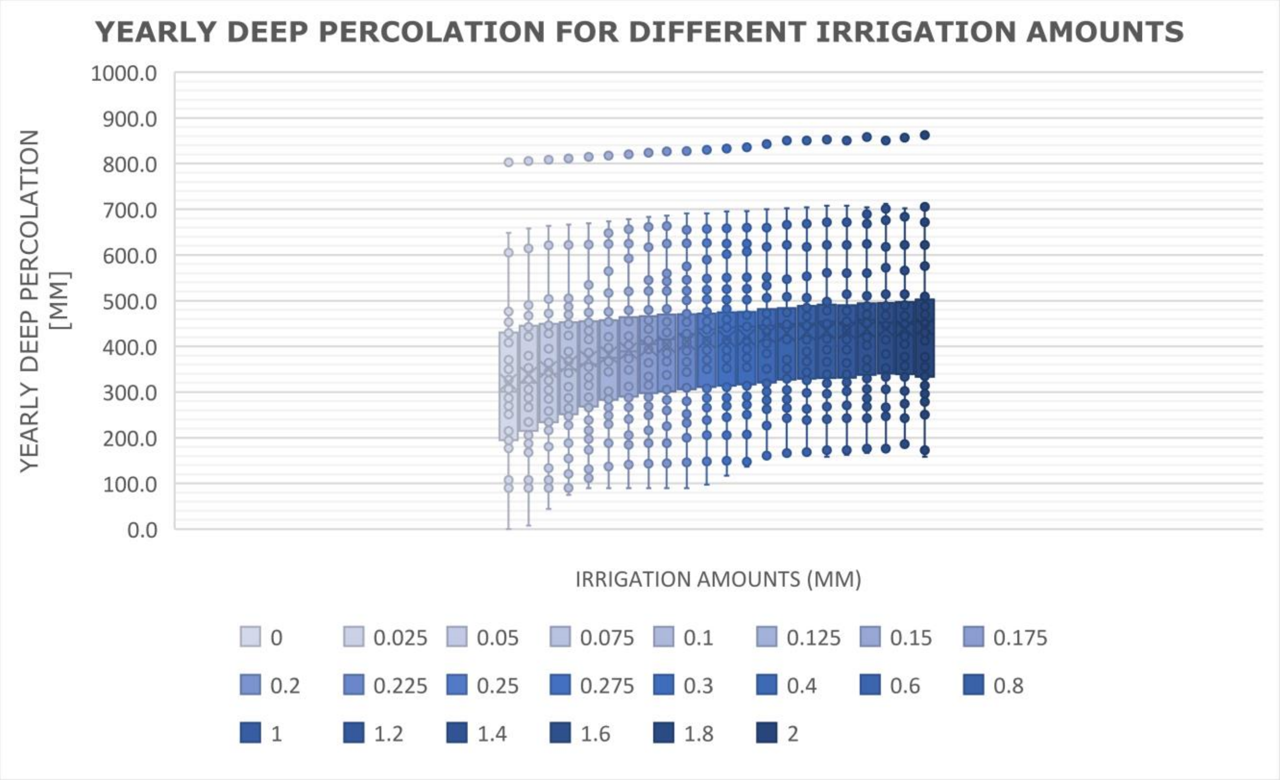

Figure 7: Scatter in yearly deep percolation in mm, for different amounts of irrigation in cm. The total yearly irrigation for 46 years is illustrated by dots per irrigation amount. Rooting depth is kept constant at 80 cm. Unfortunately, it was not possible to get the irrigation amounts on the x-axis, therefore the legend is situated below the x-axis.

3.5 Future scenarios

Royal Dutch meteorological institute, KNMI, produces climate scenarios for the Netherlands for the future. It is important to note that they are possible future scenarios, not forecasts. Each of the four scenarios is possible as they differ per future greenhouse gas emission. The change in greenhouse gas emissions determines the change in worldwide temperature and change in airflow patterns. The scenarios describe the average weather and the likelihood of extreme weather events. However, for this research only the yearly increase in precipitation and potential evapotranspiration are used. The climate scenarios are based on the sources IPCC (KNMI, n.d.). The key figures from KNMI contain valuable information for the future scenarios made in 2014 (KNMI, 2014). The factors for precipitation and potential evapotranspiration are summarized in table 2. In figure 8 the different climate scenarios are shown which differ in terms of change in airflow and increase in worldwide temperature.

There are several reasons for this change in climate in the Netherlands. The jet stream might become weaker due to temperature difference decrease between the pools and the tropics. If the jet stream becomes weaker weather types may stay longer at the same place. This means that droughts or heatwaves might have a longer duration. Next to that, the air temperatures will rise in the Netherlands. A warmer air can hold more moisture, causing more extreme precipitation. At the most extreme precipitation events also gusts (‘valwinden’) can happen, which are dangerous and can cause damage. Due to higher temperatures and an increase in solar radiation the evapotranspiration will increase. This causes the chance of drought to increase. Climate models also show drier summer with larger precipitation deficit in the future. All scenarios show an increase in potential evapotranspiration, mainly caused by higher temperatures (KNMI, 2021). According to the KNMI for the G_H and W_H scenarios it will become drier, G_L and W_L there is no or significantly small difference (KNMI, n.d.) (KNMI, 2018).

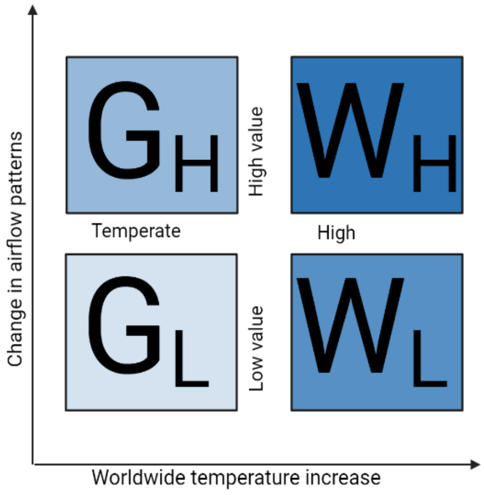

Figure 8: Future scenarios G_L, W_L, G_H, and W_H as defined by KNMI (KNMI, n.d.)

Once the model is finished, the precipitation and potential evapotranspiration can be altered to reflect the future scenarios. This is done with the factors obtained by KNMI, summarized in table 1. For each scenario the precipitation and potential evapotranspiration is multiplied with the respective factor. For the years 1954-1980 the factor of 1951-1980 is used and for the years 1981-1999 the factor of 1981-2010 is used.

Table 2: Yearly precipitation and potential evapotranspiration for 1951-1980, 1981-2010 and future scenarios G_L, G_H, W_L, and W_H. Factors are used to alter existing data for specific scenarios.

	1951-1980	**1981-2010**	**G_L**	**G_H**	**W_L**	**W_H**
Yearly precipitation [mm]	774	851	885	872	898	894
Factor compared to 1951-1980	-	-	1.14	1.13	1.16	1.15
Factor compared to 1981-2000	-	-	1.04	1.03	1.06	1.05
Yearly potential evapotranspiration [mm]	534	559	576	587	581	598
Factor compared to 1951-1980	-	-	1.08	1.10	1.09	1.12
Factor compared to 1981-2010	-	-	1.03	1.05	1.04	1.07

Another option is to use the transformation program by KNMI. It takes historical precipitation, temperature, or global radiation series daily and turns it into the climate under one of the four KNMI'14 climate scenarios for a certain time horizon (KNMI, n.d.). There are also already some transformed time series for precipitation and reference evapotranspiration.

4. RESULTS

4.1 Irrigation demand between 1954-1999

The yearly irrigation sum varies from 0.5-53 mm, which can be seen below in figure 9. The figure also shows the yearly precipitation sum.

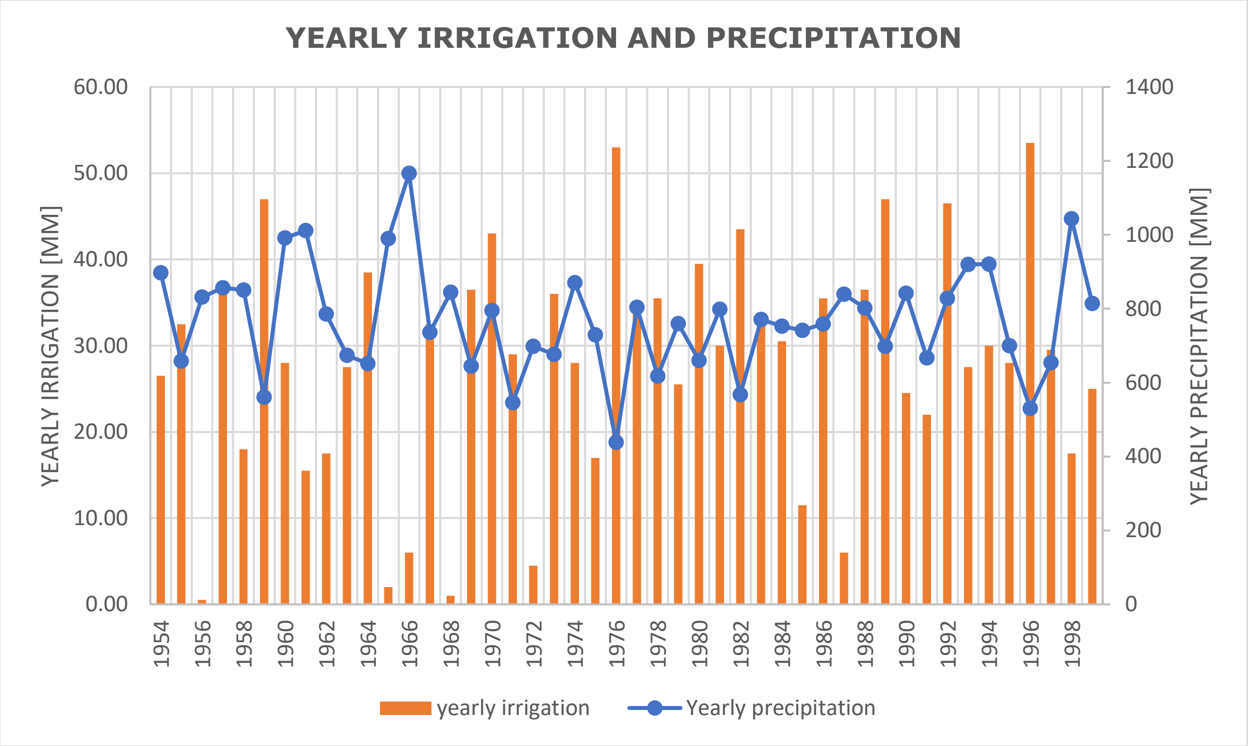

Figure 9: Yearly irrigation in mm and yearly precipitation in mm, for rooting depth of 80 cm and irrigation amount of 0.5 mm.

The three years with highest irrigation are 1959, 1976, and 1996. These three years all three also have low yearly precipitation. In 1965 and 1966 very little irrigation is applied, as expected both also have high precipitation. However, not all years with low irrigation have high precipitation. The average over these 46 years is 28.01 mm. With an irrigation amount of 0.5 mm, on average irrigation is applied 56 days (out of 145 days of growing season). In table 3 the irrigation frequency is listed. So, on average irrigation should be applied every two to three days.

Table 3: Irrigation frequency for different amounts of yearly irrigation. Irrigation frequency should be interpreted as how often irrigation should occur. An irrigation frequency of 2.9 translates to irrigation once every 2.9 (=3) days.

Yearly irrigation [mm]	5	10	15	20	25	30	35	40	45	50	55
Irrigation frequency	14.5	7.3	4.8	3.6	2.9	2.4	2.1	1.8	1.6	1.5	1.3

4.2 Irrigation demand for 2050

For all four climate scenarios the irrigation will change. See appendix table 5 for a complete list per scenario per year. In Table 4 the changes are summarised. In two scenarios, G_H and W_H the mean irrigation increases with 5.2% and 5.67% respectively. For the G_L and W_L scenarios irrigation decreases slightly when looking at the mean but will slightly increase when looking at the median.

Table 4: Total, mean, change of mean, median, and standard deviation of irrigation for 1954-1999 and for the four different climate scenarios: G_L, G_H, W_L, and W_H.

	1954-1999	**G_L**	**G_H**	**W_L**	**W_H**
Total (1954-1999) [mm]	1288.50	1281.00	1355.50	1284.00	1361.50
Mean (per year) [mm]	28.01	27.85	29.47	27.91	29.60
Change in mean (%)	100.00	99.42	105.20	99.65	105.67
Median [mm]	29.25	29.50	30.00	29.50	30.25
Standard deviation [mm]	13.33	13.52	13.59	13.50	13.52

The distribution of yearly irrigation is illustrated in figure 10. For both the G_H and W_H scenario the scatter of irrigation between years is slightly higher than the other three.

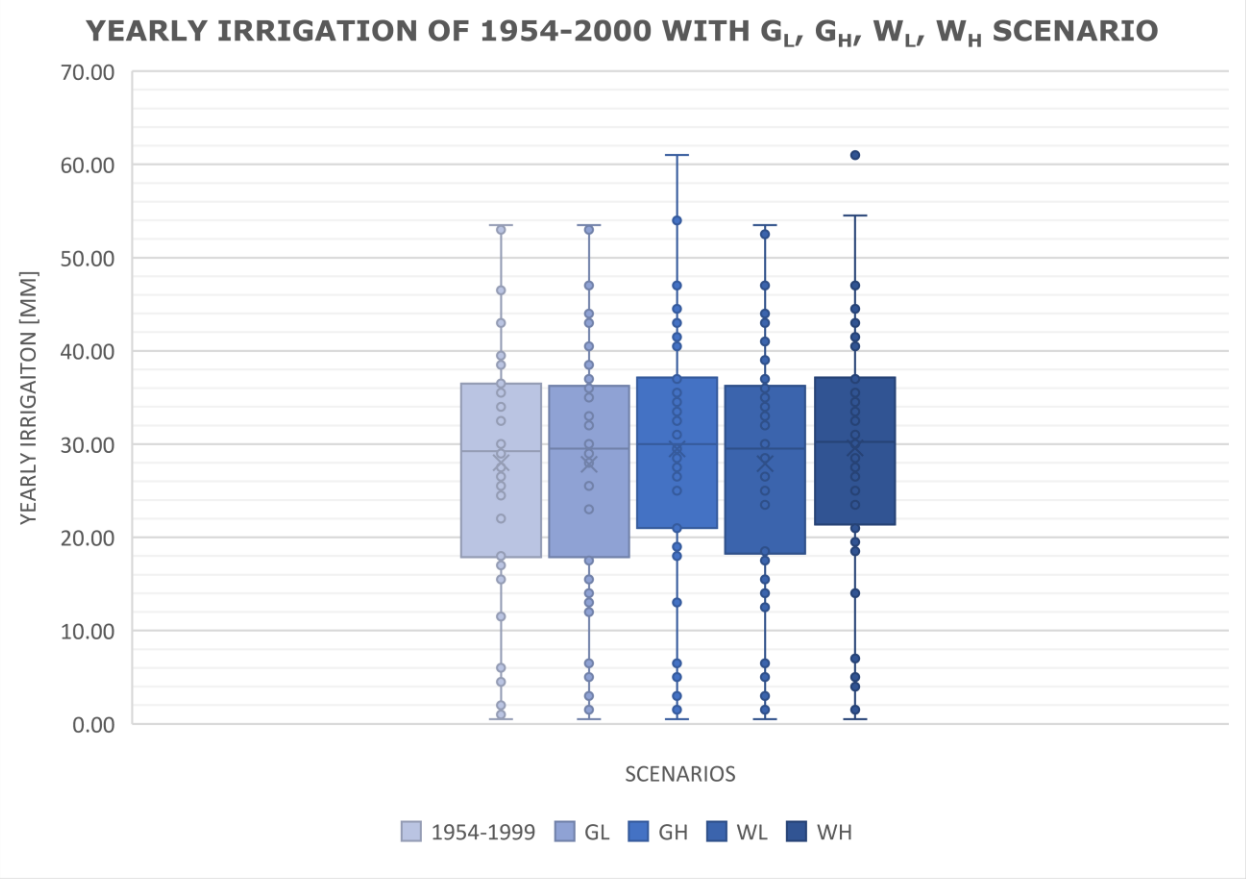

Figure 10: Scatter in yearly irrigation for 1954-1999, G_L, W_L, G_H, and W_H scenario. With rooting depth of 80 cm and an irrigation amount of 0.5 mm. Unfortunately, it was not possible to get the scenarios on the x-axis, therefore the legend is situated below the x-axis.

The lowest yearly irrigation values do not alter much for the different scenarios, while the highest irrigation does change.

5. DISCUSSION

5.1 Interpretation of results

With an increasing rooting depth, the volume where a crop potentially could get water from increases. It makes sense then that with an increasing rooting depth the total yearly irrigation decreases. For the same reason crops with higher rooting depth are also more likely to need no irrigation at all. This was also found in literature as mentioned in 3.4.

When meteorological data and other factors are similar, a higher irrigation amount leads to a higher the yearly irrigation (figure 6). When the applied irrigation amount is high and a precipitation event occurs the next day, the high amount of irrigation the day before is unnecessary. A smaller irrigation amount would have prevented drought stress, as the rainwater would decreased rootzone depletion. The soil will not be able to store the water and it will lead to the groundwater. In figure 7 this is clear. For the same reason the variability in yearly irrigation increases with increasing irrigation amounts.

Yearly the irrigation varies between 0.5 and 53 mm, with an average of 28.01 mm. The variation per year complies with the water usage data of the allotments (figure 1), although the range is bigger. The average over the 46 years is slightly higher than what was found in literature as mentioned in the introduction but falls well in between the given range. The variation per year also depends on when precipitation occurs. The total yearly precipitation can be high, but if there is no precipitation for a certain month irrigation will be high as well. As these are yearly totals, while the model is in timesteps of a day, this reflects seasonal differences.

From the four different future scenarios by KNMI only two experiences increase in irrigation. For the G_H and W_H scenario mean yearly irrigation increases by 5.2% and 5.67% respectively. For the G_L and W_L scenario the irrigation stays the same. The subscript H refers to the higher increase in airflow patterns, see figure 8. The larger change in airflow patterns means a weaker jet stream, which leads to more drought, as explained in section 3.5. This also complies with what KNMI found.

5.2 Sensitivity of model

The model is sensitive for the rooting depth. As can be seen in figures 5 the yearly irrigation mean varies between 13 mm and 53 mm. The range is big, a factor of 4. This means that when using a different rooting depth, the results will be influenced significantly. In figure 6 the sensitivity of yearly irrigation per irrigation amount is shown. The mean yearly irrigation varies from 15 mm to 121 mm. This range is even larger, a factor of 8. When using a different irrigation amount the results will be influenced significantly.

5.3 Model improvements

The used model and its values are only an approximation of the reality. Several improvements must be made to better quantify the water balance of the area. The rootzone depletion model used for this research is simplified. Firstly, an allotment does not contain only tomatoes. It has an abundant variety of crops, which should be represented in the model. Rooting depth and crop coefficient should be altered, as explained in 3.3.6. Also, the rooting depth is not a constant in real life. It varies over time and will adapt to situations as mentioned in 3.4. To improve the model the rootzone should be studied further and implemented as a variable instead of a constant. On top of that, the crop coefficient should also be more specific, as it is normally not a linear relationship which was assumed for this research.

Next to that, the number of days irrigation should be applied was very high, on average 56 days. That means that on average gardeners need to irrigate their allotment every two to three days. It is debateable that gardeners go to their allotment that often to irrigate just a tiny bit. It would be less time-consuming to increase the irrigation amount, as that will decrease the rootzone depletion more than a smaller irrigation amount.

Another important simplification that was made is the soil characteristics. The original soil is a loopodzol, however it is altered per gardener to their liking. This makes the soil highly heterogenous instead of homogenous. The values for moisture content at field capacity or wilting point will therefore also not be the same for each individual allotment. To make this more site specific each allotment should be tested, which was not feasible for this research. The 'crop coefficient' outside of growing season will also vary through time and not be constant as was assumed. On top of that, most gardeners (not all!) add mulches to the topsoil, causing more variety in soil evaporation.

For the future scenarios the factor for yearly increase in precipitation and potential evapotranspiration were multiplied on a daily basis. The seasonal changes are not incorporated by doing so. Instead of increasing the intensity of the weather, e.g., with longer periods of droughts and intense precipitation, the total precipitation amount is increased. This will likely cause the irrigation increase to be underestimated. For instance, a light shower during summer will now be slightly bigger, instead of not occurring as it might be in the future. By using a more specific climate scenarios this problem can be omitted. For instance, the KNMI data transformation program as mentioned in 3.5. However, in this transformation program the original data could not be transformed. Therefore, it was chosen to use the original data and the yearly factors. To improve, the model could be run with data from KNMI from a different weather station and the respective climate scenarios. Another factor that is not considered is the increase in length of the growing season, due to climate change. This will influence the rootzone depletion model as well. Plants will be able to grow earlier and be able to continue growing longer.

Another simplification that is made is the irrigation amount. At the allotments there is no irrigation machinery, people water their crops by hand. As humans are more prone to error, the water will be distributed less equally over the area. Gardeners could calculate how many litres of water they should apply by using their area and then distribute that as equally as possible over their crops, preferably as close to the roots as possible. The number of times a gardener must apply irrigation varies, but in some years, it is as much as every 1-2 days. It is not likely that a gardener will have time to visit their allotment that often. A larger irrigation amount would in that case be better, even though more water will be lost to deep percolation.

In the model, rainfall interception is ignored. For this research there was too little time to incorporate it into the model. When further research is done this could be incorporated. Overland flow is also ignored because the allotments are considered flat. Again, too little time was present to incorporate it, for further research it could incorporated. As rainfall interception and overland flow decrease the amount of precipitation that effectively is available to the crop, incorporating rainfall interception and surface runoff will increase the irrigation demand.

5.4 Advise gardeners

Based on this research some practical advice for the gardeners is listed. First, gardeners should choose crops that can root deep. The optimization procedure shows that this decreases irrigation. Another measure could be to check the deeper layers of soil for moisture. The topsoil can look dry but the deeper soil layers might contain moisture. Checking weather forecasts to see if precipitation will occur can also decrease irrigation. Soil can store water, so irrigating when not necessary is not sustainable. Another advice is to irrigate as little as possible per irrigation event. This research has shown that decreasing the irrigation amount has significant effects on the yearly irrigation demands. If manually irrigating often is too demanding, considering drip irrigation or agreement with allotment neighbours might be a solution. Lastly, as mentioned in the introduction, it will be more successful to set rules about sustainable water use. Just raising awareness does not necessarily decrease irrigation, so imposing rules on one’s own irrigation use will be more effective.

6. CONCLUSION

The irrigation demand of private allotments at the Wageningse Eng is quantified through the rootzone depletion model. It was found that the model is dependent on the rooting depth and the irrigation amount applied. A rooting depth of 80 cm in combination with an irrigation amount of 0.5 lm^{-2} best matches the current data of water usage by the allotments. The irrigation varies per year, with over 46 years an average of 28.01 mm/year. With the small irrigation amount gardeners should on average water every two to three days. For the $G_{L,}$ and W_L future scenario irrigation will not change significantly in 2050. For the G_H and W_H scenario the mean irrigation will increase to 29.47 mm and 29.60 mm respectively. The larger change in airflow patterns for G_H and W_H are most likely the reason for the increase.

So, climate change and the increasing likelihood of droughts do not necessarily mean an increase in irrigation. It is important that further research is done on the irrigation demand changes in the future.

7. ACKNOWLEDGEMENTS

Writing my BSc thesis was something I was nervous about, to be honest. Whenever I had setbacks, I had to remember myself that it is also about the learning process and not just about the result. In the end I am glad of what I learned by writing my thesis. I learned to push my boundaries and trust myself academically. My supervisor Klaas Metselaar played a big part in helping me succeed. I would like to express my gratitude towards Klaas for the quick helpful reactions and weekly meetings. And, also for checking in on me personally to see how this thesis project was affecting me.

Next to that I would also like to thank the meteorology and air quality group of the Wageningen University and Research for providing the original meteorological data from the Haarweg weather station. Lastly, I would like to thank the Foundation Wageningse Eng for providing information to me. Specifically, I would like to thank Marja van der Lubbe for providing me with specific water usage data by the allotments and Marten Renkema for showing me around the allotments and the water pump.

8. BIBLIOGRAPHY

Adams, J. (1966). Influence of Mulches on Runoff, Erosion, and Soil Moisture Depletion. *Soil Science Society of America Journal*, 110-114.

AHN. (n.d.). *AHN Viewer*. Retrieved from Algemeen Hoogtebestand Nederland: https://www.ahn.nl/ahn-viewer

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (2006). *FAO Irrigation and Drainage Paper No. 56.*

Ayling, S. M., Philips, N., & Ayling, S. B. (2021). *Allotments in the Future: Building Resilience to Climate Change through Improved Site Design and Efficient Water Practices.* Bristol: MDPI.

Bakker, J., van der Lubbe, M., & Savenije, H. (2021). *Pilot project: van drinkwater naar grondwater voor de volkstuinen op de Wageningse Eng.* Wageningen.

Cornell University. (2010). *Northeast Region Certified Crop Adviser (NRCCA) Study Resources*. Retrieved from Cornell University: https://nrcca.cals.cornell.edu/soil/CA2/CA0212.1-3.php

Döll, P. (2022). Impact of climate change and variability on irrigation requirements: a global perspective. *Climatic Change*, 269-293.

Egerer, M. H., Lin, B. B., & Philpott, S. M. (2018). Water Use Behavior, Learning, and Adaptiation to Future Change in Urban Gardens. *Frontiers in Sustainable Food Systems*.

Fischer, G., Tubiello, F. N., Velthuizen, H., & Wiberg, D. A. (2006). Climate change impacts on irrigaiton water requirements: Effects of mitigation, 1990-2080. *Technological Forecasting and Social Change*, 1083-1107.

Fulton, J. M. (1970). Relationship of root extension to the soil moisture level required for maximum yield of potatoes, tomatoes and corn. *Canadian Journal of Soil Science*, 92-94.

Google. (2022, April 2). Retrieved from Google Maps: https://www.google.com/maps/@51.9807017,5.6766168,4316m/data=!3m1!1e3!5m1!1e4?hl=nl

KNMI. (2014). *KNMI'14 Klimaatsneario's - Kerncijfers*. Retrieved from knmi.nl: https://www.knmi.nl/nederland-nu/KNMI14_klimaatscenarios/kerncijfers

KNMI. (2018, March 23). *Klimaat bericht Late start natuur*. Retrieved from knmi.nl: https://www.knmi.nl/over-het-knmi/nieuws/late-start-natuur

KNMI. (2018, July 3). *Toekomstige zomers mogelijk droger dan gedacht*. Retrieved from knmi.nl: https://www.knmi.nl/over-het-knmi/nieuws/toekomstige-zomers-mogelijk-droger-dan-gedacht

KNMI. (2021, October 25). *KNMI Klimaatsignaal'21*. Retrieved from knmi.nl: https://www.knmi.nl/kennis-en-datacentrum/achtergrond/knmi-klimaatsignaal-21

KNMI. (n.d.). *Droogte*. Retrieved from KNMI: https://www.knmi.nl/kennis-en-datacentrum/uitleg/droogte

KNMI. (n.d.). *KNMI'14 Klimaatscenario's - Transformatieprogramma*. Retrieved from knmi.nl: https://www.knmi.nl/nederland-nu/KNMI14_klimaatscenarios/transformatieprogramma

KNMI. (n.d.). *KNMI-klimaatscenario's*. Retrieved from knmi.nl: https://www.knmi.nl/kennis-en-datacentrum/uitleg/knmi-klimaatscenario-s

Minasny, B., & McBratney, A. B. (2018). Limited effet of organic matter on soil available water capacity. *European Journal of Soil Science*, 39-47.

Nachabe, M. H. (1998). Refining the Definiton of Field Capacity in the Literature. *Journal of Irrigation and Drainage Engineering*.

Nikolaou, G., Neocleous, D., Christou, A., Kitta, E., & Katsoulas, N. (2020). Implementing Sustainable Irrigation in Water-Scarce Regions under the Impact of Climate Change. *Agronomy*.

Orsini, F., Kahane, R., Nono-Womdim, R., & Gianquinto, G. (2013). Urban agriculture in the developing world: a review. *Agronomy for Sustainable Development*, 695-720.

pdok. (n.d.). Retrieved from pdok/viewer: https://app.pdok.nl/viewer/?origin=pdoknl

Pratt, T., Allen, L. N., Rosenberg, D. E., Keller, A. A., & Kopp, K. (2019). Urban agriculture and small farm water use: Case studies and trends from Cache Valley, Utah. *Agricultural Water Management*, 24-35.

Rutten, E. R. (2019, 7 6). Hoogleraar: 'Drinkwater gebruiken voor je tuin bij droogte is beschamend'. *De Gelderlander*, p. 8.

Schwalbe, Z. (n.d.). *Understanding Plant Water Use: Evapotranspiration (ET)*. Retrieved from Colorado State University: https://coagmet.colostate.edu/extended_etr_about.php#:~:text=Evapotranspiration%20is%20the%20water%20loss,through%20the%20leaves%20of%20plants.

Stichting Wageningse Eng. (2022). *missie en visie*. Retrieved from wageningseeng: http://wageningseeng.nl/wie-zijn-wij/missie-en-visie/

Tracy, S. R., Black, C. R., Roberts, J. A., Sturrock, C., Mairhofer, S., Craigon, J., & Mooney, S. J. (2012). Quantifying the impact of soil compaction on root system architecture in tomato. *Annals of Botany*, 511-519.

van der Lubbe, M. (2022, 5 6). Oppervlakte volkstuinen & huidig watergebruik. Wageningen.

Vitens. (n.d.). *Waterhardheid*. Retrieved from Vitens.nl: https://www.vitens.nl/over-water/waterhardheid?Postcode=6706KJ

Wösten, J. V. (2001). *Waterretentie- en doorlatendheidskarakteristieken van boven- en ondergronden in Nederland: de Staringreeks.* Wageningen: Alterra, Research Instituut voor de Groene Ruimte.

9. APPENDICES

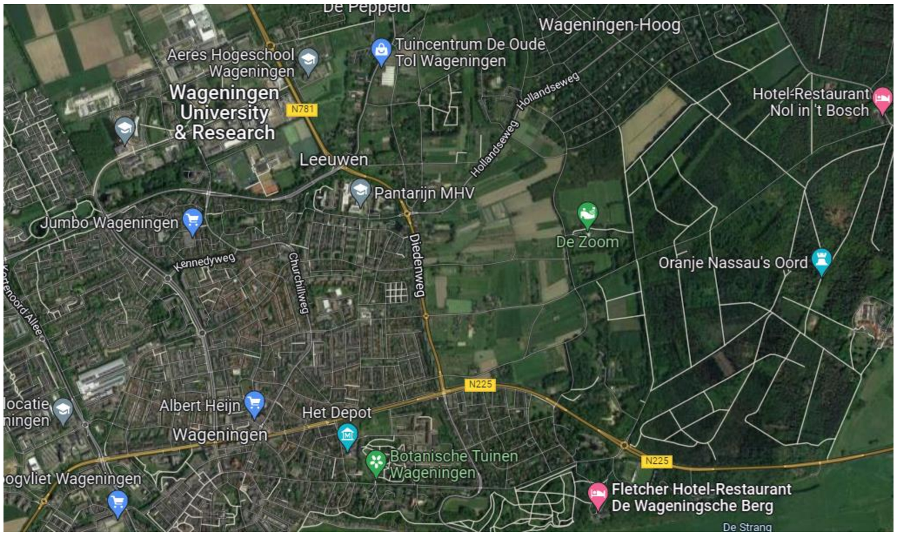

Figure 11: General overview of the allotment locations at Wageningse Eng **(Google, 2022)**

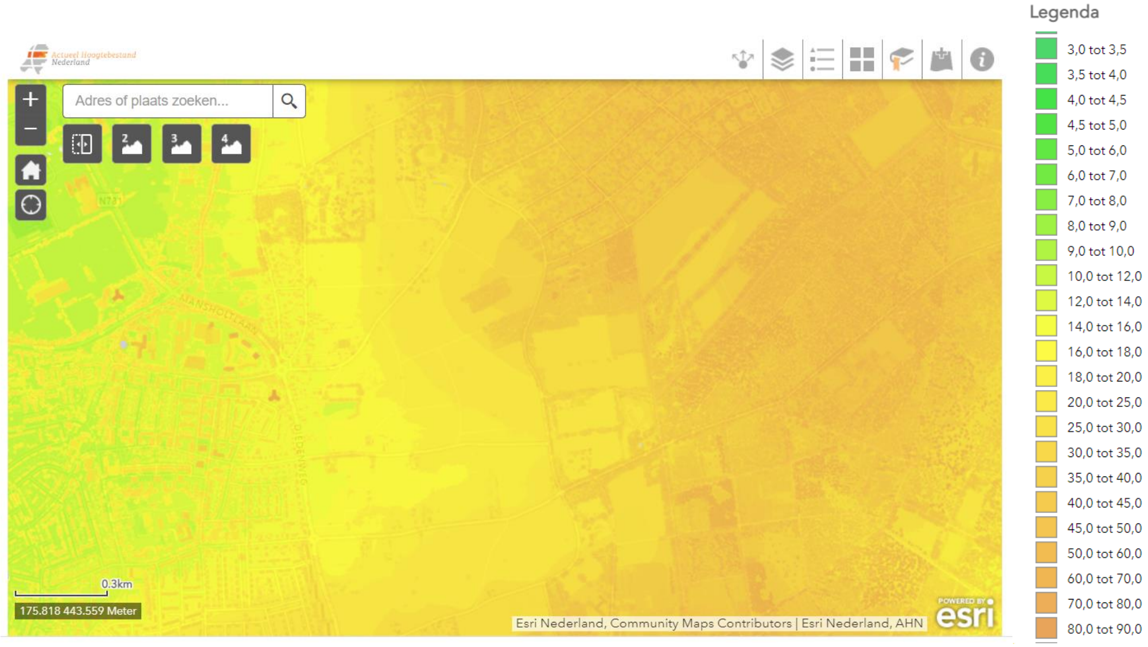

Figure 12: Height profile of Wageningse Eng and surroundings **(AHN, n.d.)**

Table 5: Yearly irrigation in mm for 1954-1999 and the four future scenarios (G_L, G_H, W_L, and W_H).

year	1954-1999	G_L	G_H	W_L	W_H
1954	26.50	25.50	28.50	25.50	28.50
1955	32.50	33.50	34.50	34.00	34.50
1956	0.50	0.50	0.50	0.50	0.50

1957	36.50	35.50	37.00	35.50	37.00
1958	18.00	18.00	21.00	18.50	21.50
1959	47.00	47.00	47.00	47.00	47.00
1960	28.00	14.00	25.00	14.00	23.50
1961	15.50	13.00	18.00	13.00	18.50
1962	17.50	17.50	21.00	17.50	21.00
1963	27.50	28.00	30.00	28.50	30.00
1964	38.50	38.50	40.50	39.00	41.00
1965	2.00	3.00	3.00	3.00	4.00
1966	6.00	6.50	6.50	6.50	7.00
1967	32.50	32.00	33.50	32.00	34.00
1968	1.00	1.50	1.50	1.50	1.50
1969	36.50	37.00	37.00	37.00	37.00
1970	43.00	43.00	43.00	43.00	43.00
1971	29.00	28.50	30.00	28.50	30.00
1972	4.50	5.00	5.00	5.00	5.00
1973	36.00	36.00	36.00	36.00	36.00
1974	28.00	25.50	29.50	25.00	30.00
1975	17.00	15.50	19.50	15.50	19.50
1976	53.00	53.50	54.00	53.50	54.50
1977	34.00	35.00	35.50	35.00	35.50
1978	35.50	35.50	37.50	35.50	37.50
1979	25.50	26.00	26.50	26.50	26.50
1980	39.50	40.50	41.50	41.00	41.50
1981	30.00	30.50	33.50	30.00	33.50
1982	43.50	44.00	44.50	44.00	44.50
1983	33.00	33.00	33.00	33.00	33.00
1984	30.50	30.50	31.00	30.50	31.00
1985	11.50	12.00	13.00	12.50	14.00
1986	35.50	35.50	35.50	35.50	35.50
1987	6.00	6.50	7.00	6.50	7.00
1988	36.50	37.00	40.50	37.00	40.50
1989	47.00	47.50	47.50	47.50	47.50
1990	24.50	25.50	26.50	25.50	26.50
1991	22.00	23.00	25.00	23.50	25.00
1992	46.50	47.50	47.50	47.50	47.50
1993	27.50	28.00	29.50	28.50	30.00
1994	30.00	30.00	30.00	30.00	30.50
1995	28.00	29.00	29.00	29.00	29.00
1996	53.50	53.00	61.00	52.50	61.00
1997	29.50	30.00	32.50	30.00	32.50
1998	17.50	18.00	19.00	18.50	20.00
1999	25.00	25.50	27.50	25.00	27.50