# A Conceptual project of the irrigation system at the municipality of Malinska-Dubašnica on the Island of Krk

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MASTER THESIS

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FACULTY OF CIVIL ENGINEERING

Master in Civil Engineering, Hydraulic Engineering

Computational Hydraulics

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# A CONCEPTUAL PROJECT OF THE IRRIGATION SYSTEM AT THE MUNICIPALITY OF MALINSKA-DUBAŠNICA ON THE ISLAND OF KRK

## MASTER THESIS

Supervisor: Associate professor Vanja Travaš, PhD, University of Rijeka

Co - Supervisor: Reinhard Nolz, Priv.-Doz. Dipl.-Ing. Dr., University of Natural Resources and Life Sciences, Vienna

VIENNA, JUNE 2020.

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Name of the study: **University Graduate Study Programme in Civil Engineering**
Scientific area: Technical sciences
Scientific field: Civil Engineering
Area of science: Hydraulic engineering

Master thesis theme

**A CONCEPTUAL PROJECT OF THE IRRIGATION SYSTEM AT THE MUNICIPALITY OF MALINSKA-DUBAŠNICA ON THE ISLAND OF KRK**

Candidate: **MONIKA DELAČ**

Course: **COMPUTATIONAL HYDRAULICS**

Master thesis number: **H-2020-23**

**Task:**

The candidate's task is to create a conceptual project of the irrigation system at the municipality of Malinska - Dubašnica, island of Krk. At the given location, the candidate must predict the location of a mini accumulation and must create a technical solution for the given irrigation system. Stored water of the system will be used to irrigate multitude of agricultural crops. The crops will be defined by the mentor. The candidate must determine the water quantity needed and the dynamics of the irrigation for the conceptual project. The data received must be used to define the necessary volume of the mini accumulation. The candidate in the following step will need to distribute and dimension the water distribution pipeline to the locations needed to be irrigated. For each location the candidate must optimize the irrigation system and dimension it. It is necessary to do dimensioning of the pump station and mini accumulation. To finish, the candidate will have to prove the cost-effective irrigation hypothesis in the area of question by producing an approximate cost estimate for the proposed design solution and comparing the costs with the projected benefits of building such a system.

**The topic of the paper was assigned on:** February 11, 2020

**Mentor:**

Associate professor Vanja Travaš, Ph. D.

## STATEMENT

I wrote my diploma thesis independently, in cooperation with a mentor and under consideration of positive building regulations and scientific achievements in the field of civil engineering. The Faculty of Civil Engineering in Rijeka holds the intellectual property rights to this work.

Monika Delač

Rijeka, July 2, 2020

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Thank you!

Vienna, June 2020. Monika Delač

## ABSTRACT AND KEYWORDS

In this Diploma thesis is showed a conceptual project of the irrigation system on a 32 hectares gross area at the Municipality of Malinska-Dubašnica on the island Krk. This study presents a technical solution for the given irrigation system. Computer program CROPWAT 8.0 was used to calculate crop irrigation water requirement and irrigation schedule for an average and dry year. Hydraulic analysis of irrigation systems is prepared using computer softer EPANET 2.0.

Finally, the thesis presents a cost-effective irrigation hypothesis by producing an approximate cost estimation for the proposed design solution and compare the costs with the projected benefits of building such a system.

KEY WORDS: Irrigation system, CROPWAT 8.0., EPANET 2.0., Island Krk.

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# 1. Introduction

Irrigation could be defined as the watering of land by artificial mean as a purpose to foster the agricultural production. Effective irrigation will influence the entire growth process from seedbed preparation, germination, root growth, nutrient utilization, plant growth to the regrowth, yield, and quality.

The basic criteria for introducing irrigation to an agricultural area is suitable soil, the amount of available water, clearly expressed interest of end users, economic and financial justification. The island of Krk has relatively large areas suitable for agricultural development, mostly within smaller or larger karst fields. On the site of interest, Dubašnica field is in the hinterland of Vantačići and Porat in the Municipality of Malinska-Dubašnica. According to the regulation of the Municipal spatial plan, these are agricultural areas larger than 100 hectares. Soil is classified as valuable agricultural soil (terra rossa) and can only be used for the development of agricultural production. In total, it is estimated that 134 hectares are located within the Dubašnica field, of which 32 hectares are intended for the development of irrigation systems. The beneficiaries are local residents.

Irrigation in the Republic of Croatia is not a measure of realizing the possibility of agricultural production, but of ensuring the continuity of production and protection against drought. In the Republic of Croatia, there is a program for the development of irrigation systems that primarily begins with a survey of locals who must express interest in at least 70% of respondents to initiate the design process or first pre-investment studies that then show return on investment. Thus, it is necessary to establish the benefit of irrigation with the economic selection criterion. If the project leads to higher economic benefits given that there is no irrigation system, the project can be started.

The problem with irrigation so far has been the availability of water, respectively the problem is that the water used from the water supply is pre-conditioned and whose price is higher than the water used for such systems (e.g. rainwater).

The aim of this diploma thesis is to create a conceptual project of the irrigation system on a 32 hectares gross area at the Municipality of Malinska-Dubašnica on the island Krk. This study will present a technical solution for the given irrigation system. Computer program CROPWAT 8.0 was used to calculate crop irrigation water requirement and irrigation schedule for an average and dry year. Hydraulic analysis of irrigation systems is prepared using computer softer EPANET 2.0.

Finally, the thesis will prove the cost-effective irrigation hypothesis by producing an approximate cost estimation for the proposed design solution and compare the costs with the projected benefits of building such a system.

# 2. General features of the area

## 2.1. Topographic features

Krk is a Croatian island in the northern Adriatic Sea, located near Rijeka in the Bay of Kvarner and part of Primorje-Gorski Kotar county. Krk is the largest Adriatic island, with an area of 405.80 $km^2$, and it is connected to the mainland by the Krk Bridge. The highest peak is Obzova (569 meters above the sea). Krk is part of the Primorje-Gorski Kotar County and has a total of 68 settlements, which are administratively divided into seven local self-government units, the City of Krk and municipalities: Baška, Vrbnik, Punat, Dobrinj, Malinska-Dubašnica, and Omišalj. The municipality of Malinska-Dubašnica is located in the northwestern part of the island Krk (Figure2.).


***Figure 1.*** *Position of the island of Krk with the administrative boundaries of municipalities and cities [12.].*

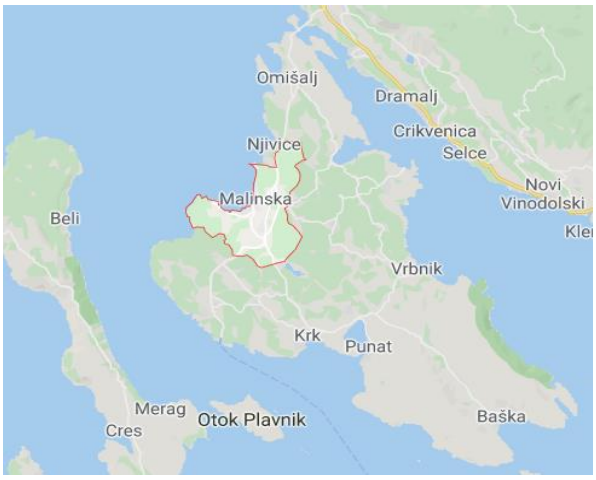


***Figure 2.*** *Position of the the municipality of Malinska-Dubašnica (taken from google maps).*

The population of the municipality is mostly concentrated along the gulf coast. Malinska-Dubašnica has 3,134 inhabitants, and the settlement itself has 965 inhabitants. The height profile of the municipality is diverse - from sea coasts up to 220 m above sea level in the southern part of the municipality.

The most important roads at the municipality are the state road 102 Smrika - the town of Krk - Baška and the state road 104 St. Ivan - Valbiska.

## 2.2. Climate features

The island of Krk is located in a temperate climate zone where winters are mild and summers are warm with a mild and pleasant Mediterranean climate. The average annual air temperature is 14.16 °C. The hottest months of the year are May, June, August, and September. The average summer air temperature is 22.8 °C and the sea temperature is 23-25 °C. The coldest months of the year are December, January, and February. During these months temperatures below 0 °C also occur. The coldest month is January and the warmest is July. According to Köppen-Geiger, climate classification is Cfa-moderately warm and humid climate with hot summers. Figure 3. represent geographical distribution of Köppen-Geiger climate types in Croatia in the 1961–1990 period. (Cfa = moderately warm and humid climate with hot summers; Cfb = moderate warm and humid climate with warm summers; Csa = Mediterranean climate with hot summers; Csb = Mediterranean climate with warm summers; Df = humid boreal climate).

The main winds are bura, jugo and maestral. According to the number of sunny hours per year (2,500), Krk is one of the sunniest parts of Europe.

Precipitation is not properly distributed - most occur during the autumn and least during the summer when dry periods occur. The average rainfall for the area of the Malinska is between 1,070 and 1,090 mm.

In addition to the rainfall amount, the distribution of rainfall is significant for agricultural production, especially in the vegetation period of 1.4. - 30.9. The rainiest months in the area of the island are usually autumn and winter, respectively from August to April. Less precipitation usually falls between January and March and June and July.

The northern and northwestern parts of the island generally have higher rainfall during the year than other parts of the island. In the summer there is the least rainfall, then there is a lack of soil moisture causing stagnation and sometimes interruption of vegetation. The occurrence of hail is rare, occurring every four to five years.

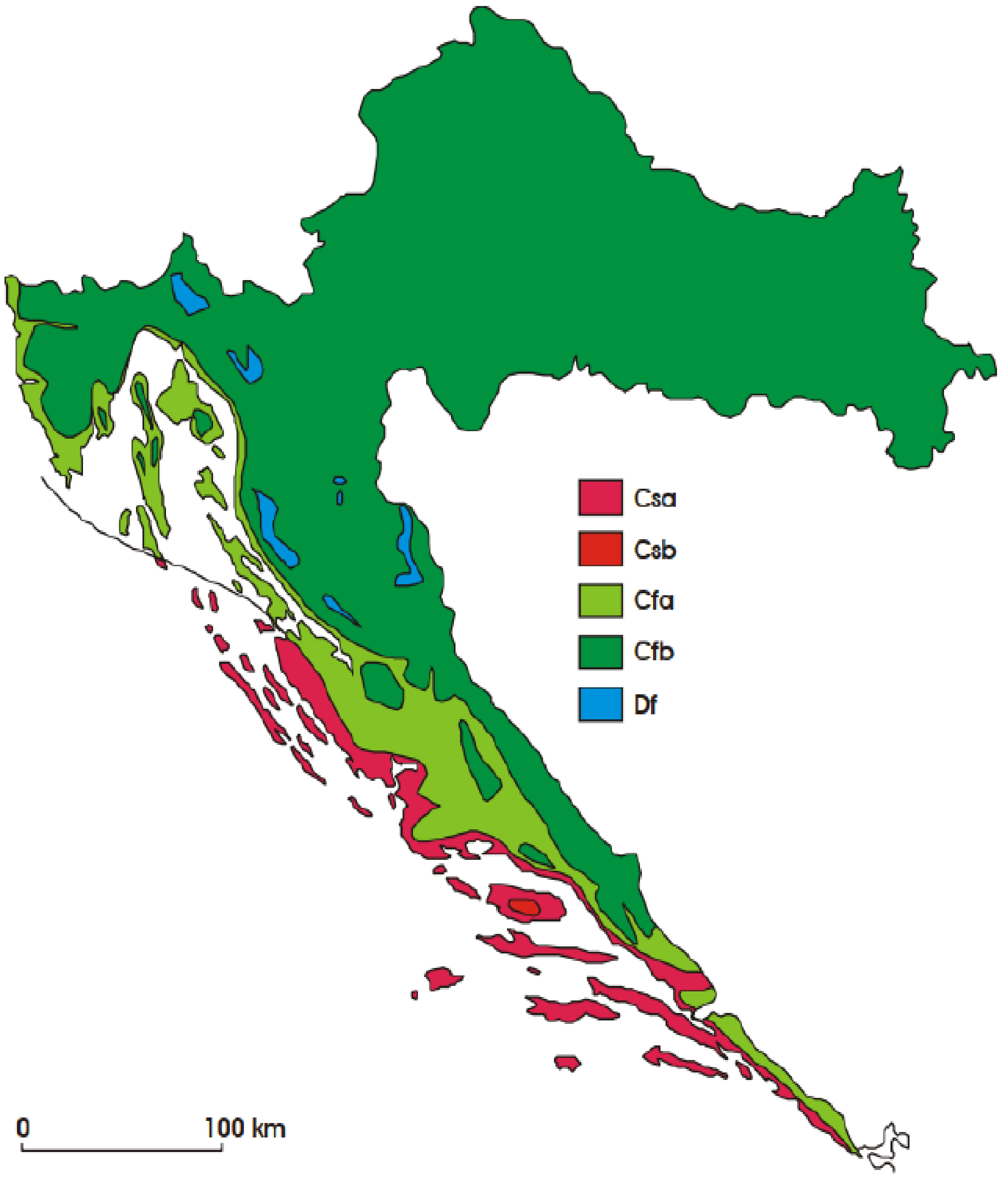


***Figure 3.*** *Geographical distribution of Köppen-Geiger climate types in Croatia in the 1961–1990 period. (Cfa = moderately warm and humid climate with hot summers; Cfb = moderate warm and humid climate with warm summers) [13.].*

## 2.3. Hydrogeological and hydrological features

The island of Krk and all Kvarner area is a part of the Other Dinarides and it is situated in the NW part of large Mesozoic Adriatic Carbonate Platform.

The oldest sedimentary rocks cropping out on the surface are Lower Cretaceous limestones and dolomites found on the western and southwestern part of the island. A minor part of the surface is covered with transitional Lower–Upper Cretaceous dolomites and diagenetic breccias, while rudist limestones outcrops of Upper Cretaceous are visible the most of the Island (Figure 4.). Paleocene-Eocene foraminiferal limestones sporadically overlay Cretaceous carbonates. Eocene siliciclastic rocks with properties of flysch (mostly marls and siltstones and sandstones in alteration) dominate along with the structure, stretching from Omišalj Bay to Baška Valley, which divides the island and is considered as Palaeogene syncline. Oligocene-Miocene carbonate breccias (Jelar breccias) overlay on Cretaceous and Paleogene rocks occur only in the southwestern part of the Island. The youngest Pleistocene deposits sporadically covered carbonate and siliciclastic bedrocks: terra rossa, slope deposits and proluvial fans.

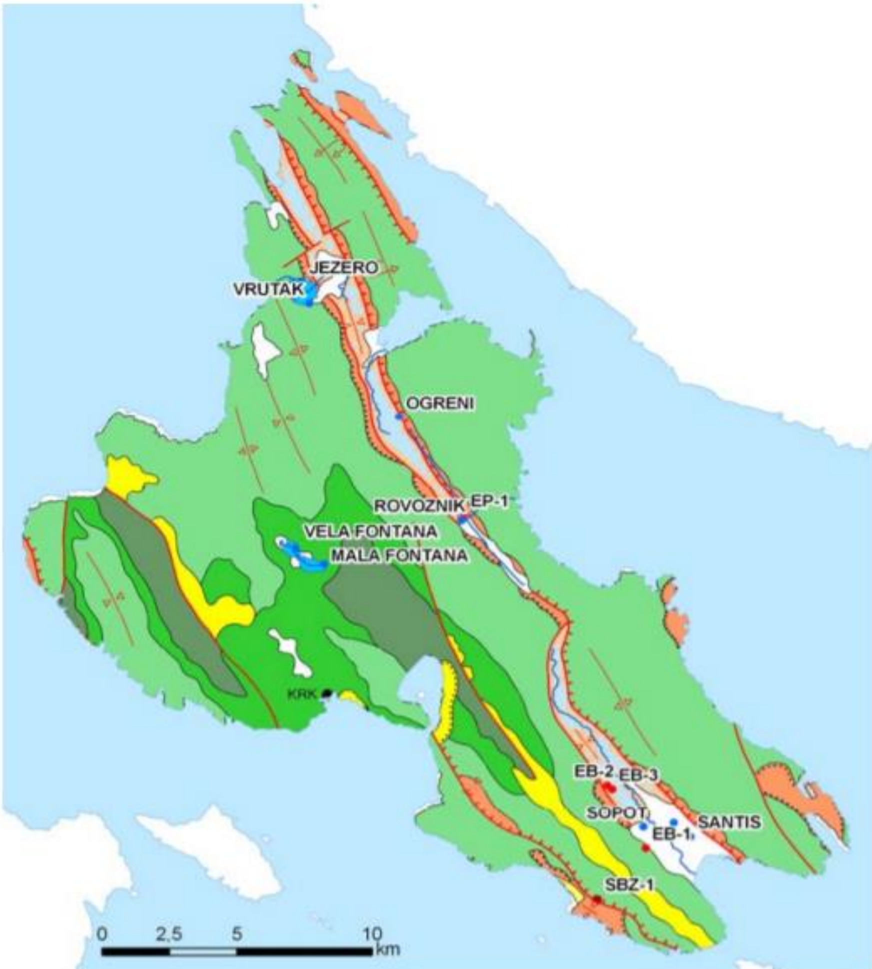


***Figure 4***. *Geological map of Krk and the most important water resources used for water supply [9.].*

Hydrogeological properties of rocks are the following: limestone rocks are fractured and deeply karstified and for this reason, are mostly well permeable. Dolomite and limestone breccias that are not tectonically fractured and are classified as less permeable rocks, while Paleogene siliciclastic rocks are considered as impermeable. The limestone rock mass is strongly karstified. The depth of karstification is more than -40 m due to longstanding lower sea-level during Pleistocene. In the central karst zone, the most important water resources and springs used in the water supply are placed. These water resources are Ponikve reservoir and Lake Njivice, springs and intakes of groundwater in Baška valley, Vrbničko polje and area of Dobrinj (Figure 4).

The water supply of the Island of Krk was for a long time-resolved by combining the surface and groundwater resources. That is by intakes of springs in the area of Baška, Vrbnik and Dobrinj settlements; by intake of surface water of Lake Njivice and in Ponikve area, firstly by the intake of groundwater, and after the construction of the reservoir by the intake of surface waters penetrated in the karst groundwater.

Ponikve reservoir is formed in the karst depression located in the central part of the island. It is a karst valley that is app 2000 m long and 150-450 m wide. Its bottom is covered by Quaternary deposits thickness up to approximately 44,4 m. Due to the geomorphological shape and the altitude this location represents the base for the local flow. So, groundwater and surface waters from the surrounding cathment area are flowing to Ponikve. At the lowest part of the karst valley is a ponor zone with its lowest part at 7 m above sea level. Therefore, even in the natural conditions, this depression was periodically flooded and was dried during dry periods by draining through ponor zone. Groundwater tracing proved that water sinking through the abyss zone is occurring on coastal springs in the area of Malinska.

## 3. The current and planned state of the irrigation area

The agricultural land covered by this study is in the area of Dubašnica within the Municipality Malinska-Dubašnica, in the northwestern part of the island of Krk (Figure 5.).

The current state of irrigation in the area of question is a local type, farmers with own reservoirs irrigate surfaces. Most of the farmland in the Dubašnica field is used as pasture and meadows, but also vegetable production, olive growing, viticulture, and fruit growing. The implementation of the Malinska-Dubašnica irrigation system with an irrigated area of 32 hectares, it is expected to change production structures and an increase in agricultural output (Figure 6.).

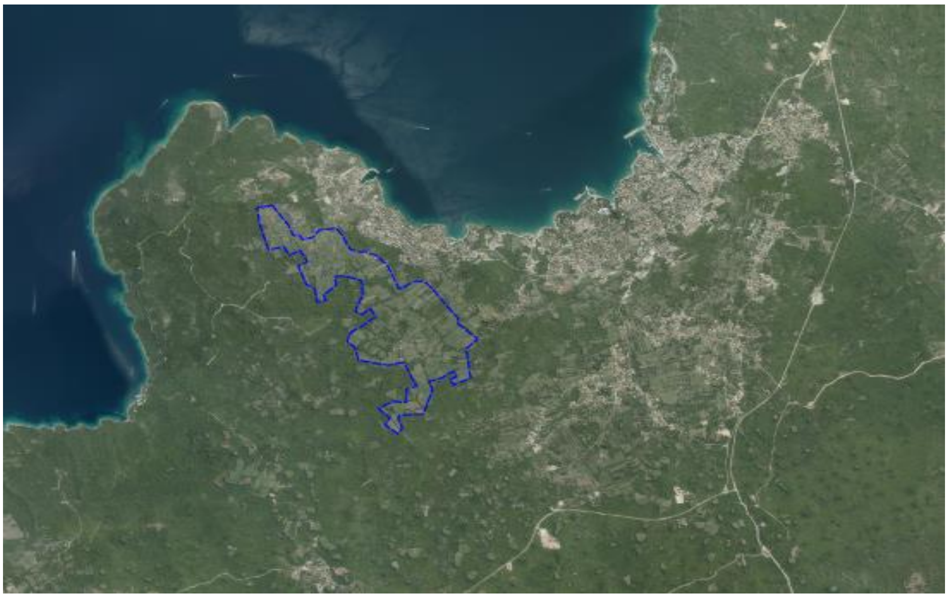

***Figure 5**. Location of the agricultural land at the Malinska- Dubašnica (taken from digital orthophoto map).*

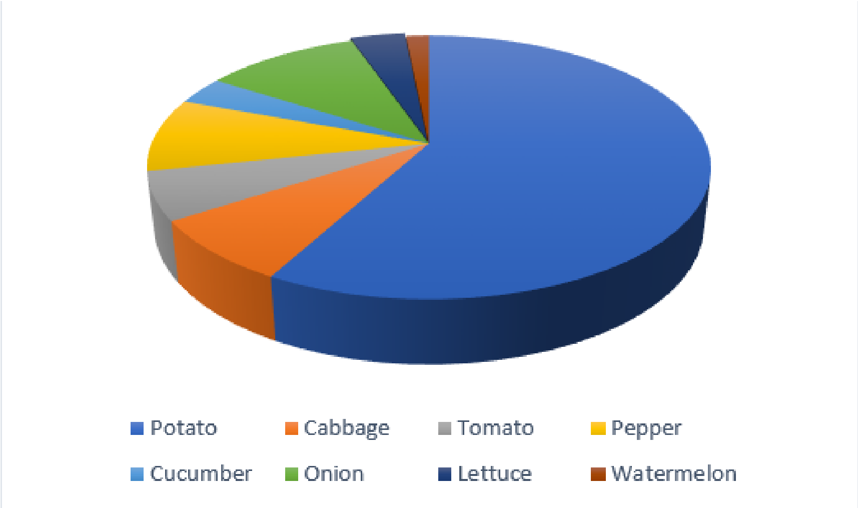


***Figure 6.** The planned structure of agricultural production (potato – 18.6 ha, cabbage – 2.5 ha, tomato – 1.9 ha, pepper - 2.9 ha, cucumber - 1.1 ha, onion – 3.4 ha, lettuce – 1.2 ha, watermelon – 0.5 ha)*

## 4. Determination of preliminary coverage of irrigation systems

The preliminary area of coverage is taken from the Substrate for the Development of Agricultural Production in the Dubašnica Field. According to this document, the area within the boundaries covers an area of 134 ha, but as intended irrigation, only 32 ha part of the area is planned to be irrigated.

LPIS (Land Parcel Identification System) is a system that provides information on agricultural land use. It is a GIS system based on orthophotographs or digital maps, and it has been established for the entire Croatian territory. According to LPIS, the current state of agriculture use is shown in Figure 7.

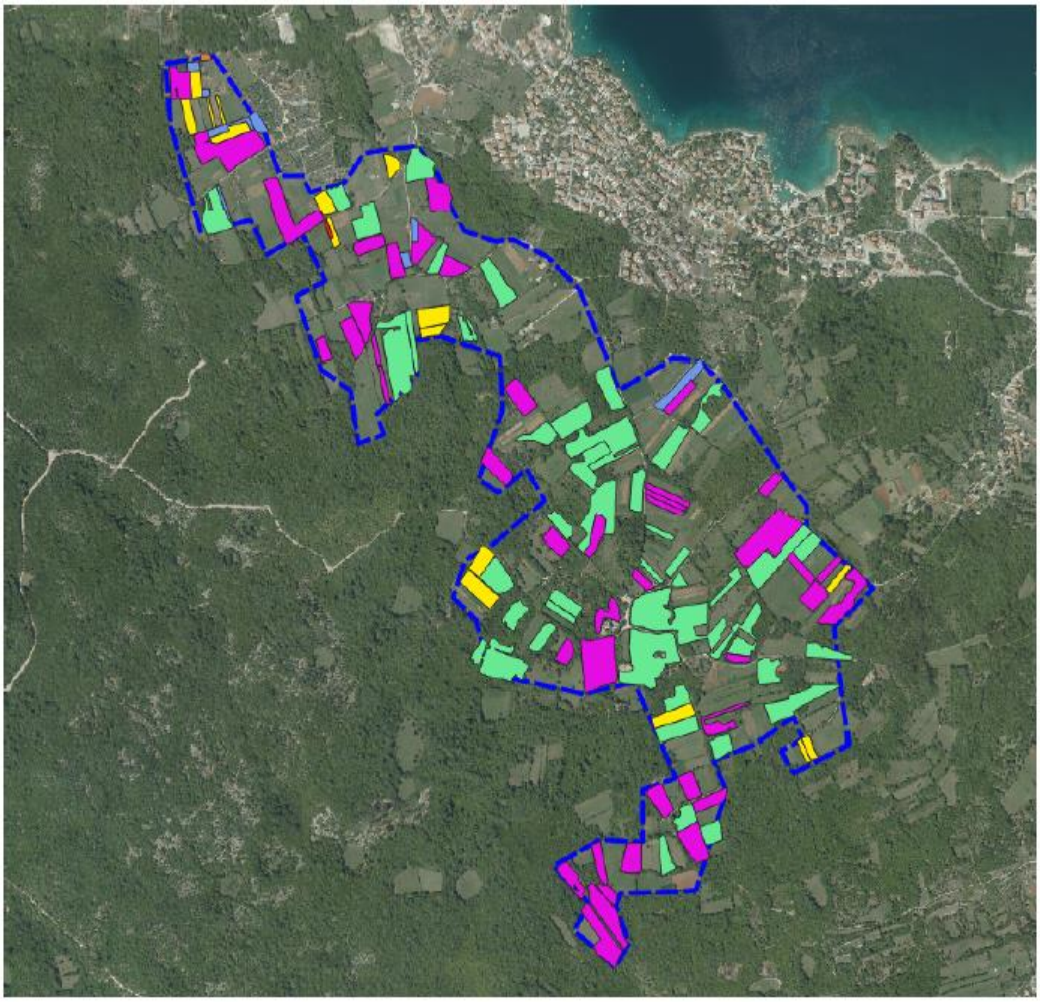

***Figure 7.*** *The land parcel of the irrigation system according to LPIS [14.].*

Figure 7. shows land parcel of the irrigation system according to LPIS. Green area (21,62 ha) - karst pasture, purple area (16.61 ha) – meadow, yellow area (3,45 ha) - arable land, red area (0,04 ha) – vineyard, blue area (0,34 ha) - olive grove, brown area (0,06 ha) – orchard.

## 5. Integration of the irrigation system in the spatial planning documentation

The spatial planning documentation relevant to the area of study is the Spatial Plan of the Municipality of Malinska-Dubašnica (PPUOMD). According to the PPUOMD, the area of study is mostly located within the protected coastal area of the sea (1000 m from the coastline), for those areas some restrictions are valid.

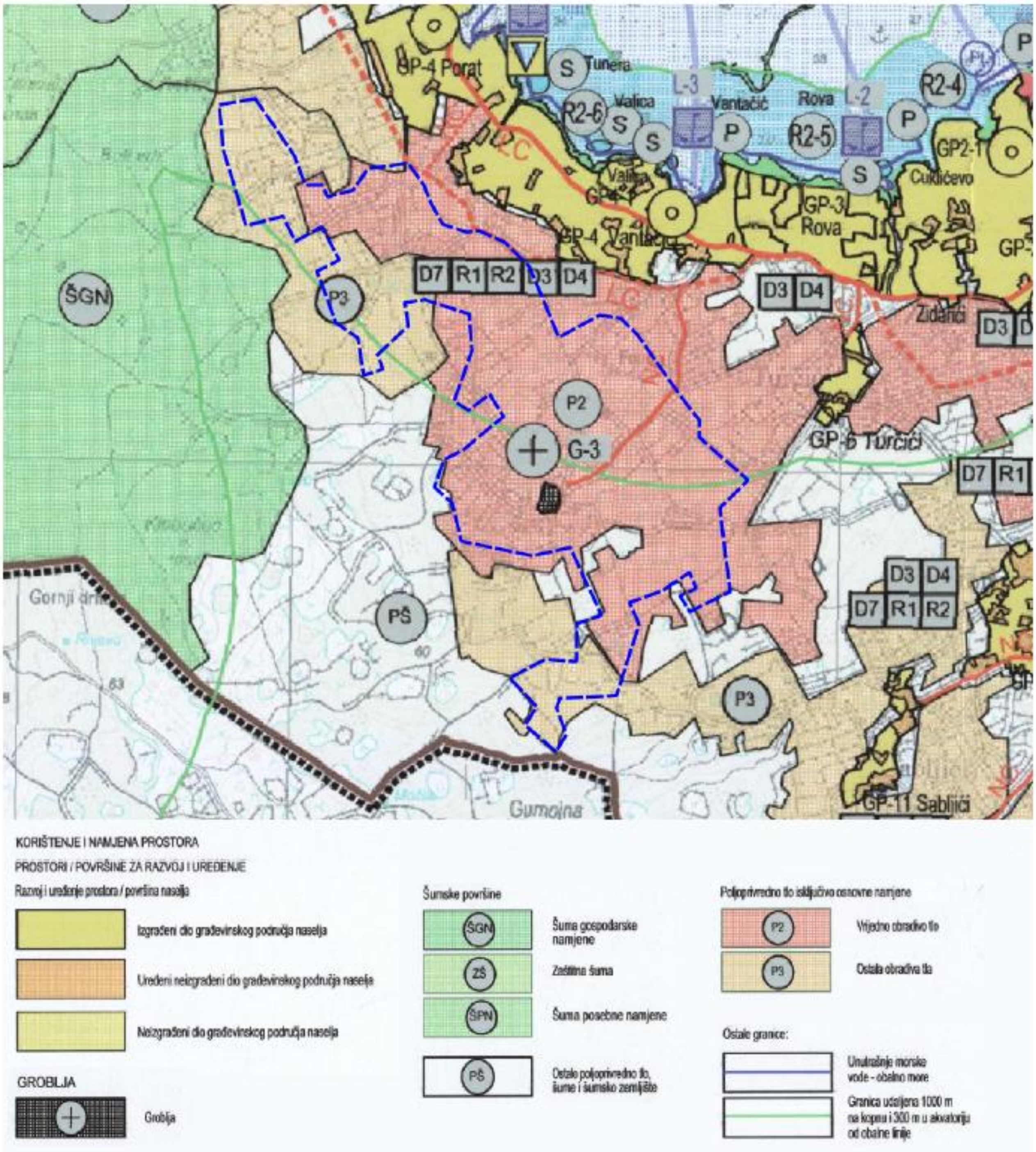

***Figure 8.*** *Using and land use according to Spatial Plan of the Municipality of Malinska-Dubašnica, the area of study is bounded by a blue dashed line [14.].*

Figure 8. represent using and land use of the area of study according to the PPUOMD. It is evident that the land area of question mainly refers to valuable arable agricultural land (code P2 according to Croatian Agricultural Land Act NN 20/2018, 115/2018), while a smaller part is arable land (P3) and other agricultural lands (PŠ).

According to PPUOMD, agricultural soils P2 and P3 are classified in category $I$ of protection, thus limiting the use of these areas to agricultural production, and only construction of buildings for agricultural purposes and the necessary infrastructure is allowed. The purpose of the restriction is to protect existing agricultural land or to prevent the conversion of land to construction or other purposes, all with the aim of developing the production of traditional agricultural crops in an environmentally satisfactory manner. According to the PPUOMD, there are also protected swamps around the area of study, shown in Figure 9. Due to their importance for maintaining certain ecological systems, swamps are protected as a natural monument and therefore cannot be used, for example, as a source of irrigation water.

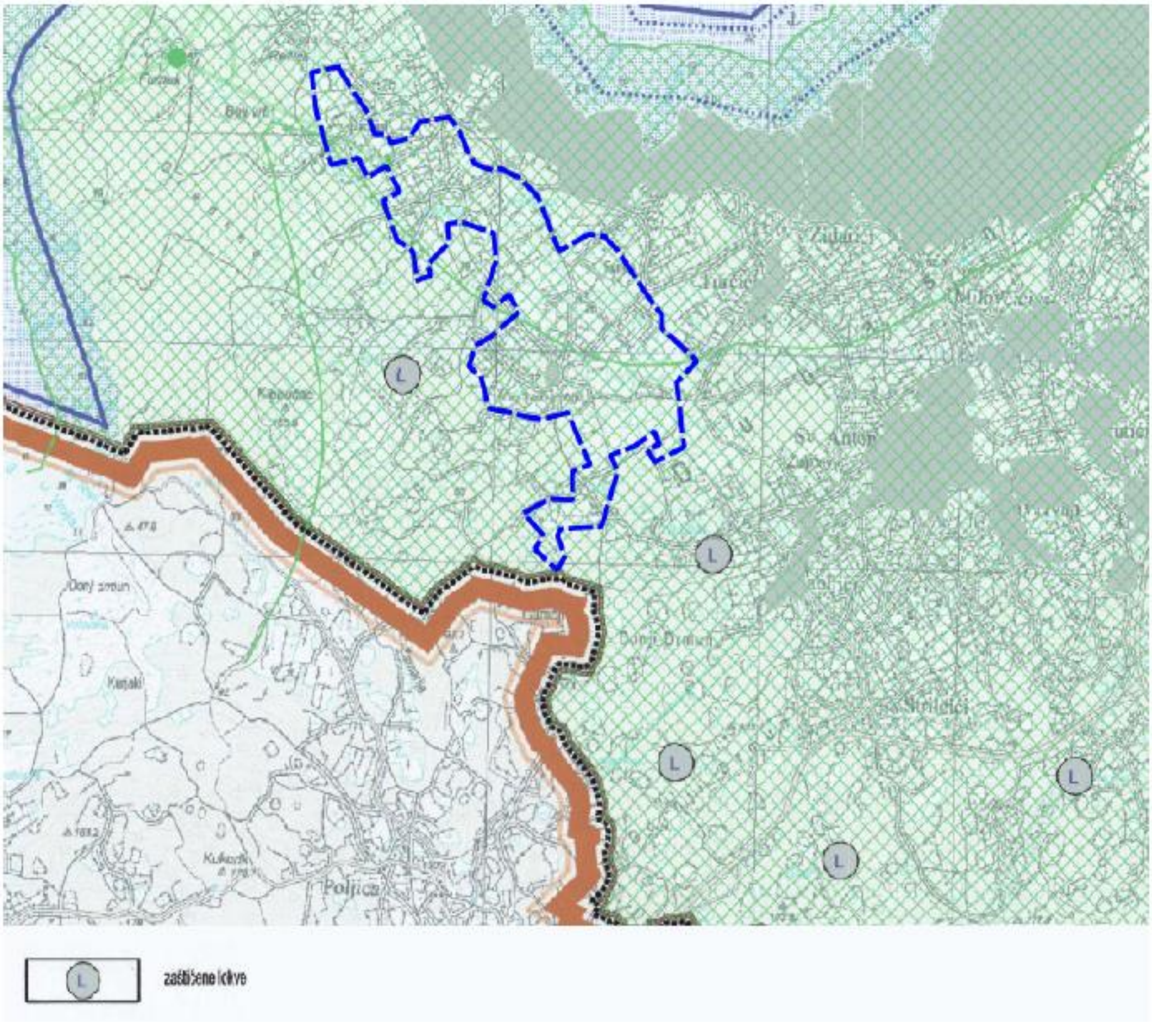


***Figure 9.*** *Conditions of use and protection of space - areas of special limitations in use according to PPUOMD, the area of study is bounded by a blue dashed line, code L represent protected swamps [14.].*

# 6. Agriculture

## 6.1. Assessment of present soil for irrigation

The soil at the municipality of Malinska – Dubašnica, island of Krk is classified as red soil - terra rossa. Terra rossa is a reddish clayey to silty–clayey soil especially widespread in the Mediterranean region, which covers limestone and dolomite in the form of a discontinuous layer ranging in thickness from a few centimeters to several meters. Its bright red color is a diagnostic feature and results from the preferential formation of hematite over goethite, known as rubification. Figure 10. represent distribution of terra rossa soils in Croatia.

Terra rossa has slightly alkaline to neutral pH and an almost completely saturated base complex dominated by calcium or/and magnesium as dominant cations. It is well drained because it is well aggregated due to high content of exchangeable calcium and magnesium, and it is situated on highly permeable carbonate rocks.

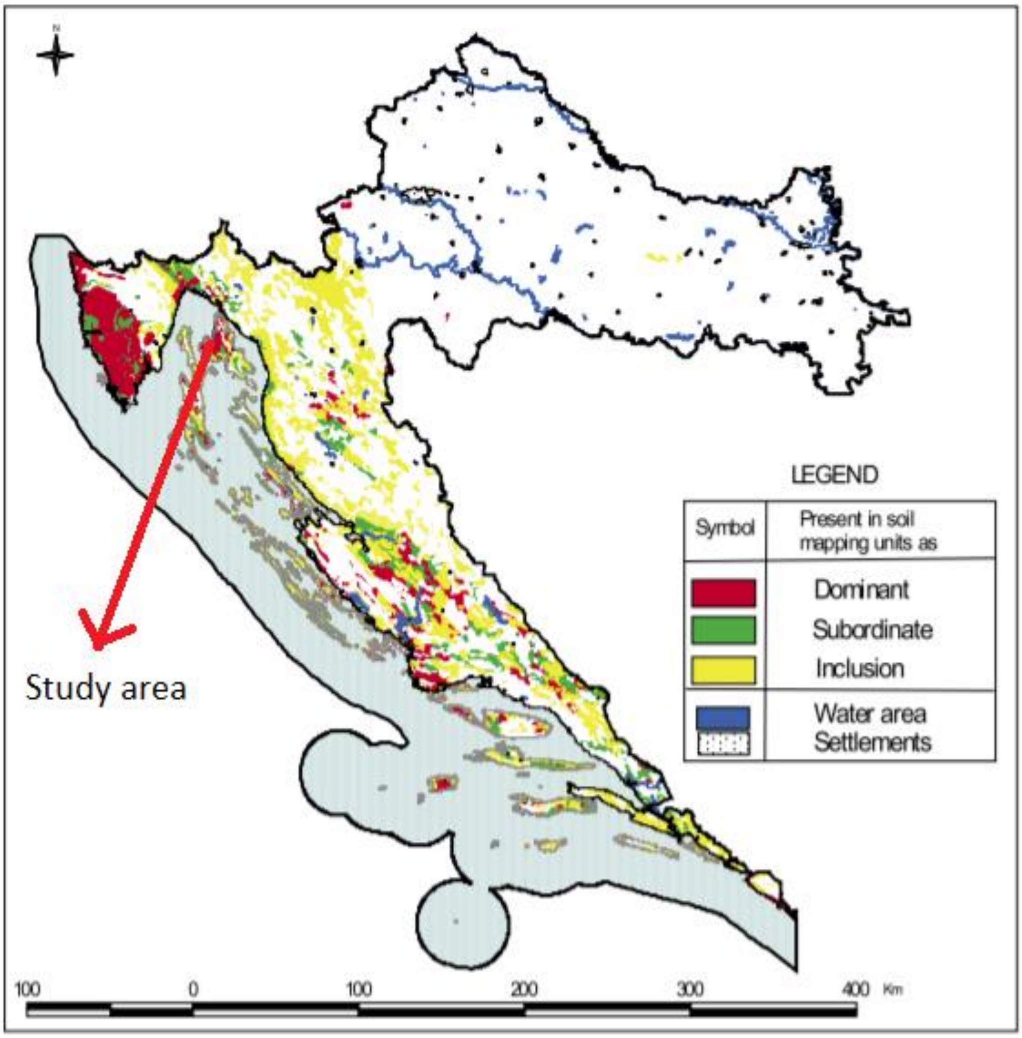


***Figure 10.*** *Distribution of terra rossa soils in Croatia [5.].*

On the site of interest, soil is classified as a red deep and red medium deep soil. Terra rossa in Malinska is composed predominantly of clay (<2 µm) and silt (2–63 µm) sized particles, with sand (>63µm) particles forming less than 4% (Figure 11.). The clay content ranges from 32.1% to 77.2% and generally increases with depth in the profiles.

Red soil contains large amounts of predominantly kaolin clay with a little vermiculite, but yet so high a clay content that, if properly managed, the stable structure of this soil is the basis of very favorable physical properties - water holding capacity, infiltration of rain water, and thermal properties. The soil is warm, loose, and permeable to water. Red soil has a favorable ratio of micro and macro pores, good permeability to rain water, and aeration. The water-holding capacity is high. Degree of saturation is above 80%.

This type of soil has a particularly good characteristic for growing crops in agriculture. All Mediterranean cultures are successfully grown on red soil, exceptionally high quality.

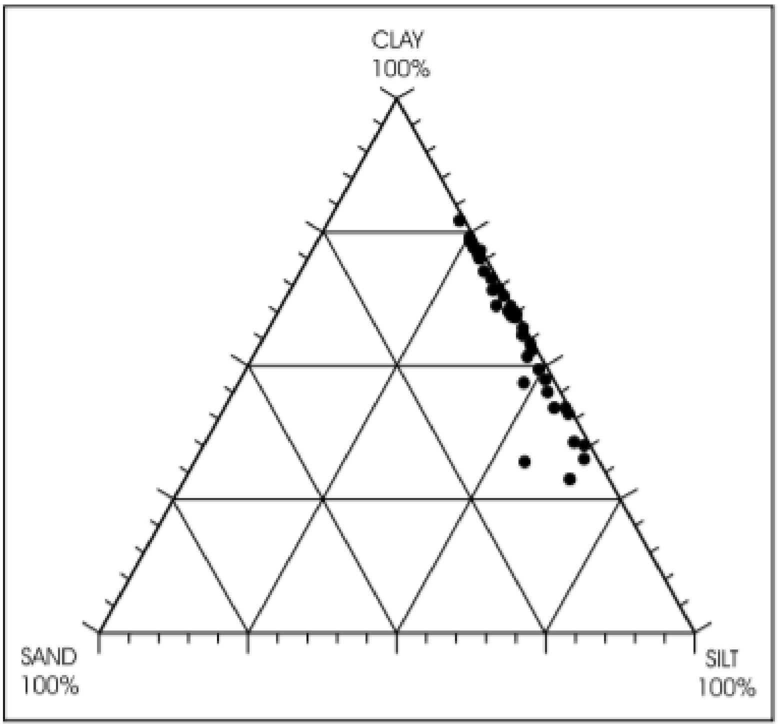


***Figure 11.*** *Particle size analysis of terra rossa [2.].*

## 6.2. Water need for optimal plantation growth

The crop water need is defined as the amount of water needed by the various crops to grow optimally and depends on the climate, crop type and on the growth stage of the crop. In this diploma thesis CROPWAT 8.0 was used to calculate reference evapotranspiration ($\mathrm{ET_0}$), effective precipitation ($\mathrm{P_{eff}}$) and crop water requirement (CWR).

CROPWAT 8.0 is a decision-support computer program based on a number of equations, developed by the FAO to calculate reference evapotranspiration ($ET_0$), crop water requirement (CWR), irrigation scheduling, and irrigation water requirement (IR), using rainfall, soil, crop, and climate data. The program includes general data for various crop features, local climate, and soil properties and helps improve irrigation schedules and the computation of scheme water supply for different crop patterns under irrigated and rainfed conditions.

Four types of data are required for using the CROPWAT software, namely, rainfall data, climatic data, soil data, and crop data. Climatic data for twenty-nine years (1976–2005) were gathered from the Rijeka Meteorological Station, obtained from the Irrigation of Primorsko-Goranska Country. Climatic parameters are monthly maximum and minimum temperature [°C], wind speed [km/h], mean relative humidity [%], sunshine hours [h], rainfall data [mm], and effective rainfall [mm].

The crop data for potato, cabbage, tomato, pepper, cucumber, onion, lettuce and watermelon were obtained from the FAO Manual and were added to the CROPWAT program, including rooting depth, crop coefficient, critical depletion, yield response factor, and length of plant growth stages. Planting dates were taken according to the guide to agricultural operations in Dubašnica.

The soil parameters obtained from the FAO CROPWAT 8.0 model include detailed information on the soil near the climatic station, such as total available moisture content, initial moisture depletion, maximum rain infiltration rate, and maximum rooting depth. Table 1. contains data about the eight crops in this diploma thesis.

***Table 1****. Data for the eight crops in this diploma thesis.*

| **Crops** | **Scientific name** | **Planting date** | **Critical Depletion Fraction** | **Rooting Depths [m]** | **Crop growth periods (days)** | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Initial | Crop Develop | Mid-Season | Late Season |
| **potato** | *Solamum tuberosum* | III | 0,35 | 0,60 | 30 | 35 | 50 | 30 |
| **cabbage** | *Brassica spp.* | III-VII | 0,50 | 1,20 | 40 | 60 | 50 | 15 |
| **tomato** | *Lycopersicon esculentum* | IV-V | 0,40 | 1,50 | 30 | 40 | 45 | 30 |
| **pepper** | *Capsicum spp.* | IV-V | 0,30 | 1,00 | 30 | 35 | 40 | 20 |
| **cucumber** | *Cucumis sativus* | V-VI | 0,50 | 1,20 | 20 | 30 | 40 | 15 |
| **onion** | *Allium cepa* | II-III | 0,30 | 0,60 | 15 | 25 | 70 | 40 |
| **lettuce** | *Lactuca sativa var. capitata* | II-VIII | 0,30 | 0,50 | 20 | 30 | 15 | 10 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **watermelon** | *Citrullus lanatus* | V | 0,40 | 1,50 | 20 | 30 | 30 | 30 |

### 6.2.1. Reference evapotranspiration ($ET_0$)

Evapotranspiration (ET) is an important process by which water is transferred from the land to the atmosphere by evaporation from the soil and by transpiration from living plants.

The rate of ET from a hypothetical crop with a height of 0.12 m, albedo 0.23, and fixed canopy resistance 70 [s/m] is called the reference evapotranspiration, $ET_0$. The Windows CROPWAT model uses the FAO Penman–Monteith equation for the calculation of the $ET_0$ where most of the parameters are measured from the weather data. The Penman–Monteith equation form is as follows:

$$\lambda ET = \frac{\Delta\,(R_n - G) + P_a C_p \frac{(e_s - e_a)}{ra}}{\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)} \quad (1)$$

where $R_n$ is the net radiation, $G$ is the soil heat flux, $(e_s - e_a)$ is the vapor pressure deficit of the air, $P_a$ is the mean of air density at constant pressure, $C_p$ is the specific heat of the air, $\Delta$ is the slope of the relationship between saturation vapor pressure and air temperature, $\gamma$ is psychometric constant, $r_s$ and $r_a$ are the surface and aerodynamic resistances.

When the theoretical crop traits and the standard height for wind speed (2 m) are applied to calculate the "bulk" surface resistance and the aerodynamic resistance, Equation (1) can be derived as follows:

$$ET_0 = \frac{0{,}408\,\Delta\,(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0{,}34\,u_2)} \quad (2)$$

where $ET_0$ is the reference evapotranspiration [mm/day], T is the mean daily air temperature [°C] at 2 m height, $u_2$ is the wind speed at 2 m height [m/s], and $e_s$ and $e_a$ are the saturation and actual vapor pressure [kPa].

The $ET_0$ values obtained from the CROPWAT software for different months are as shown in *Table 2.* It is high in summer due to the high temperature and the highest value was in July (155,21 mm/month). It decreases in winter and the lowest value was in January (28,41 mm/month) due to the low temperature. The annual mean was 79,18 mm/month.

***Table 2.*** *Climate characteristics,* $ET_0$.

| Month | Avg Temp [°C] | Humidity [%] | Wind [km/day] | Sun [hours] | Rad [MJ/$\mathrm{m}^2$/day] | $ET_0$ [mm/month] |
|---|---|---|---|---|---|---|
| **January** | 5.6 | 65 | 165 | 3.8 | 5.6 | 28.41 |
| **February** | 6.0 | 61 | 173 | 4.8 | 8.4 | 35.74 |
| **March** | 9.0 | 61 | 163 | 5.2 | 11.8 | 57.20 |
| **April** | 12.0 | 63 | 164 | 5.8 | 15.5 | 75.91 |
| **May** | 17.1 | 62 | 147 | 7.7 | 20.1 | 111.40 |
| **June** | 20.7 | 61 | 142 | 8.7 | 22.2 | 131.11 |
| **July** | 23.4 | 56 | 153 | 9.7 | 23.1 | 155.21 |
| **August** | 23.3 | 56 | 151 | 8.9 | 20.2 | 140.74 |
| **September** | 18.8 | 64 | 152 | 6.7 | 14.5 | 90.16 |
| **October** | 14.7 | 69 | 166 | 5.1 | 9.5 | 58.15 |
| **November** | 9.8 | 67 | 177 | 3.7 | 5.9 | 37.29 |
| **December** | 6.8 | 66 | 172 | 3.3 | 4.7 | 28.89 |
| | | | | | | |
| **Average** | 13.9 | 63 | 160 | 6.1 | 13.5 | 79.18 |

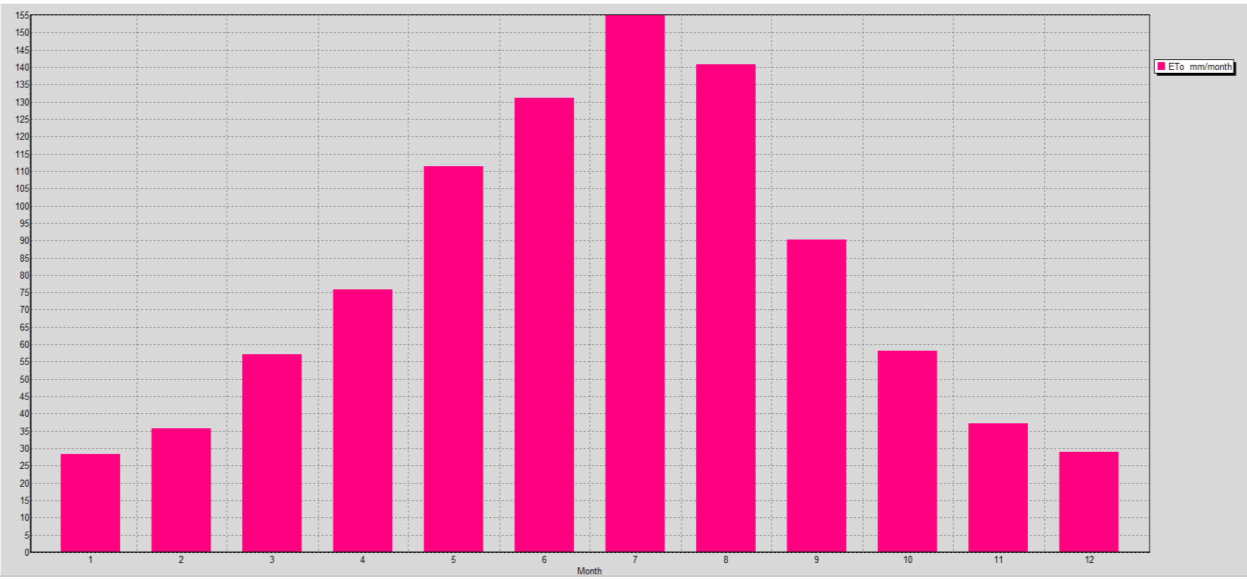


***Figure 12.*** *Annual reference evapotranspiration,* $ET_0$.

### 6.2.2. Effective precipitation, $(\mathbf{P_{eff}})$

Effective Precipitation ($P_{eff}$) is the amount of precipitation that is added and stored in the soil. During drier periods less than 5mm of daily rainfall would not be considered effective, as this amount of precipitation would likely evaporate from the surface before soaking into the ground. Effective precipitation enters the soil and becomes available to the plant.

Effective precipitation, $P_{eff}$ [mm/day] was calculated using USDA soil conversation service method. The USDA S.C.S. equation form is as follows:

$$P_{eff} = P(125 - 0,2P) \;/\; 125 \qquad for\ P \leq 250\ mm \qquad (3)$$

$$P_{eff} = 125 + 0,1P \qquad for\ P > 250mm \qquad (4)$$

where P [mm/day] is net precipitation. Net precipitation was calculated using monthly average obtained by Rijeka meteorologist station, in period from 1976 - 2005. The data was taken from irrigation plan of the Primorje-Gorski Kotar County. Net precipitation for an average year is obtained through taking an average of a sequence of the data of precipitation. Net precipitation for dry year is obtained by using an empirical probability of excess net precipitation according to Hazen. We take excess error of 75%.

Tables 3–4 and Figures 13.–14. illustrate precipitation and effective precipitation for an average and dry year.

***Table 3**. Climate characteristics, precipitation and effective precipitation for an average year.*

| Month | Rain [mm] | Eff rain [mm] |
|---|---|---|
| **January** | 134.1 | 105.3 |
| **February** | 105.3 | 87.6 |
| **March** | 108.1 | 89.4 |
| **April** | 112.8 | 92.4 |
| **May** | 96.0 | 81.3 |
| **June** | 112.5 | 92.3 |
| **July** | 63.6 | 57.1 |
| **August** | 111.0 | 91.3 |
| **September** | 163.7 | 120.8 |
| **October** | 210.4 | 139.6 |
| **November** | 184.2 | 129.9 |
| **December** | 165.5 | 121.7 |
| | | |
| **Total** | **1567.2** | **1208.6** |

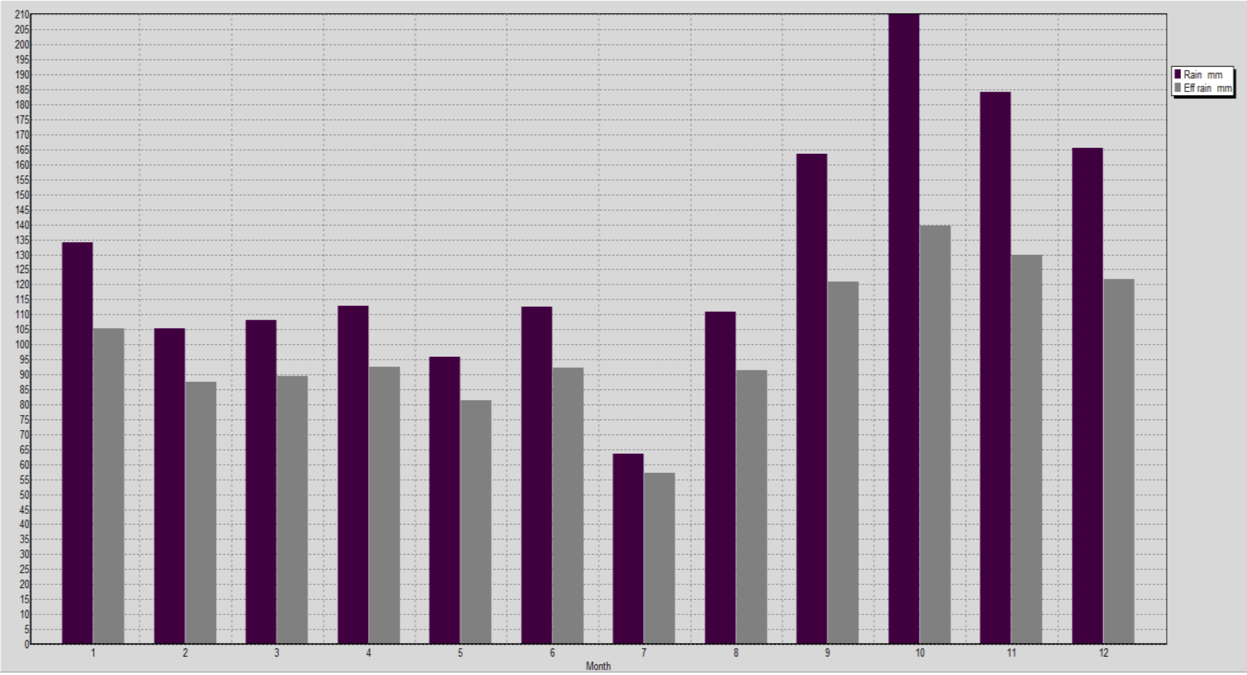


***Figure 13.*** *Precipitation and effective precipitation graph for an average year.*

***Table 4.*** *Climate characteristics, precipitation and effective precipitation for dry year.*

| **Month** | **Rain [mm]** | **Eff rain [mm]** |
|---|---|---|
| **January** | 42.1 | 39.3 |
| **February** | 51.3 | 47.1 |
| **March** | 46.0 | 42.6 |
| **April** | 84.2 | 72.9 |
| **May** | 52.4 | 48.0 |
| **June** | 76.6 | 67.2 |
| **July** | 40.6 | 38.0 |
| **August** | 65.6 | 58.7 |
| **September** | 91.2 | 77.9 |
| **October** | 117.3 | 95.3 |
| **November** | 115.6 | 94.2 |
| **December** | 108.3 | 89.5 |
| | | |
| **Total** | 891.2 | 770.6 |

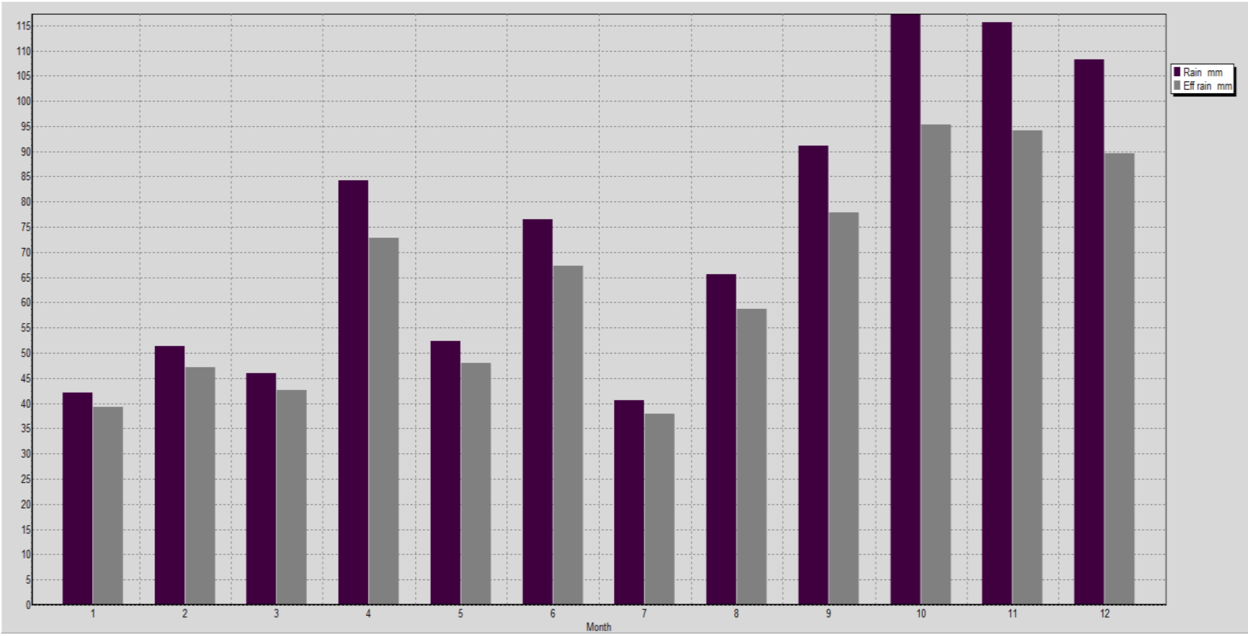


***Figure 14.*** *Precipitation and effective precipitation graph for dry year.*

### 6.2.3. Crop water requirement, CWR

The crop water requirement is the amount of water equal to what is lost from a cropped field by the ET and is expressed by the rate of ET in mm/day. Estimation of crop water requirement (CWR), is derived from crop evapotranspiration ($ET_c$) which can be calculated by the following equation:

$$ET_c = K_c \times ET_0 \quad (5)$$

where $K_c$ is the crop coefficient, and it represents an integration of the effects of four essential qualities that differentiate the crop from reference grass, and it covers albedo (reflectance) of the crop–soil surface, crop height, canopy resistance, and evaporation from the soil. Due to the ET differences during the growth stages, the $K_c$ for the crop will vary over the developing period which can be divided into four distinct stages: initial, crop development, mid-season, and late season.

Tables 5–20 illustrate crop water requirements for an average and dry year, calculated by CROPWAT.

***Table 5.*** *Water requirement per average year for potato. (Init, initial; Dev, development; Eff. Rain, effective rain; Irr.Req., irrigation requirements).*

| Month | Decade | Stage | Kc [coeff] | ETc [mm/day] | ETc [mm/dec] | Eff rain [mm/dec] | Irr. Req. [mm/dec] |
|---|---|---|---|---|---|---|---|
| **Apr** | 1 | Init | 0.50 | 1.15 | 11.5 | 30.9 | 0.0 |
| **Apr** | 2 | Init | 0.50 | 1.27 | 12.7 | 31.5 | 0.0 |
| **Apr** | 3 | Init | 0.50 | 1.44 | 14.4 | 30.0 | 0.0 |
| **May** | 1 | Deve | 0.58 | 1.89 | 18.9 | 27.7 | 0.0 |
| **May** | 2 | Deve | 0.74 | 2.65 | 26.5 | 26.1 | 0.4 |
| **May** | 3 | Deve | 0.90 | 3.45 | 38.0 | 27.6 | 10.4 |
| **Jun** | 1 | Mid | 1.02 | 4.21 | 42.1 | 31.0 | 11.2 |
| **Jun** | 2 | Mid | 1.03 | 4.52 | 45.2 | 32.9 | 12.3 |
| **Jun** | 3 | Mid | 1.03 | 4.74 | 47.4 | 28.3 | 19.1 |
| **Jul** | 1 | Mid | 1.03 | 5.03 | 50.3 | 20.8 | 29.5 |
| **Jul** | 2 | Mid | 1.03 | 5.28 | 52.8 | 15.8 | 37.0 |
| **Jul** | 3 | Late | 1.00 | 4.92 | 54.1 | 20.7 | 33.4 |
| **Aug** | 1 | Late | 0.87 | 4.13 | 41.3 | 26.8 | 14.5 |
| **Aug** | 2 | Late | 0.73 | 3.41 | 34.1 | 30.6 | 3.5 |
| **Aug** | 3 | Late | 0.65 | 2.65 | 8.0 | 9.2 | 0.0 |
| | | | | | | | |
| Total | | | | | **497.1** | **389.8** | **171.2** |

***Table 6.*** *Water requirement per dry year for potato.*

| Month | Decade | Stage | Kc [coeff] | ETc [mm/day] | ETc [mm/dec] | Eff rain [mm/dec] | Irr. Req. [mm/dec] |
|---|---|---|---|---|---|---|---|
| **Apr** | 1 | Init | 0.50 | 1.15 | 11.5 | 22.7 | 0.0 |
| **Apr** | 2 | Init | 0.50 | 1.27 | 12.7 | 26.9 | 0.0 |
| **Apr** | 3 | Init | 0.50 | 1.44 | 14.4 | 23.3 | 0.0 |
| **May** | 1 | Deve | 0.58 | 1.89 | 18.9 | 17.4 | 1.5 |
| **May** | 2 | Deve | 0.74 | 2.65 | 26.5 | 14.0 | 12.5 |
| **May** | 3 | Deve | 0.90 | 3.45 | 38.0 | 16.8 | 21.2 |
| **Jun** | 1 | Mid | 1.02 | 4.21 | 42.1 | 21.8 | 20.4 |
| **Jun** | 2 | Mid | 1.03 | 4.52 | 45.2 | 24.7 | 20.5 |
| **Jun** | 3 | Mid | 1.03 | 4.74 | 47.4 | 20.7 | 26.7 |
| **Jul** | 1 | Mid | 1.03 | 5.03 | 50.3 | 14.3 | 35.9 |
| **Jul** | 2 | Mid | 1.03 | 5.28 | 52.8 | 10.3 | 42.5 |
| **Jul** | 3 | Late | 1.00 | 4.92 | 54.1 | 13.4 | 40.7 |
| **Aug** | 1 | Late | 0.87 | 4.13 | 41.3 | 17.3 | 24.0 |
| **Aug** | 2 | Late | 0.73 | 3.41 | 34.1 | 19.6 | 14.5 |
| **Aug** | 3 | Late | 0.65 | 2.65 | 8.0 | 5.9 | 0.0 |
| | | | | | | | |
| Total | | | | | **497.1** | **268.9** | **260.4** |

*Table 7. Water requirement per average year for cabbage.*

| Month | Decade | Stage | Kc [coeff] | ETc [mm/day] | ETc [mm/dec] | Eff rain [mm/dec] | Irr. Req. [mm/dec] |
|---|---|---|---|---|---|---|---|
| **Apr** | 1 | Init | 0.70 | 1.61 | 16.1 | 30.9 | 0.0 |
| **Apr** | 2 | Init | 0.70 | 1.77 | 17.7 | 31.5 | 0.0 |
| **Apr** | 3 | Init | 0.70 | 2.02 | 20.2 | 30.0 | 0.0 |
| **May** | 1 | Init | 0.70 | 2.27 | 22.7 | 27.7 | 0.0 |
| **May** | 2 | Deve | 0.73 | 2.63 | 26.3 | 26.1 | 0.2 |
| **May** | 3 | Deve | 0.79 | 3.06 | 33.6 | 27.6 | 6.0 |
| **Jun** | 1 | Deve | 0.85 | 3.51 | 35.1 | 31.0 | 4.2 |
| **Jun** | 2 | Deve | 0.91 | 3.99 | 39.9 | 32.9 | 7.0 |
| **Jun** | 3 | Deve | 0.97 | 4.45 | 44.5 | 28.3 | 16.2 |
| **Jul** | 1 | Mid | 1.03 | 5.00 | 50.0 | 20.8 | 29.2 |
| **Jul** | 2 | Mid | 1.05 | 5.36 | 53.6 | 15.8 | 37.8 |
| **Jul** | 3 | Mid | 1.05 | 5.16 | 56.8 | 20.7 | 36.1 |
| **Aug** | 1 | Mid | 1.05 | 5.00 | 50.0 | 26.8 | 23.2 |
| **Aug** | 2 | Mid | 1.05 | 4.87 | 48.7 | 30.6 | 18.1 |
| **Aug** | 3 | Late | 1.05 | 4.28 | 47.1 | 33.8 | 13.3 |
| **Sep** | 1 | Late | 0.99 | 3.49 | 34.9 | 37.3 | 0.0 |
| **Sep** | 2 | Late | 0.95 | 2.87 | 5.7 | 8.1 | 5.7 |
| | | | | | | | |
| Total | | | | | **603.1** | **459.8** | **197.2** |

*Table 8. Water requirement per dry year for cabbage.*

| Month | Decade | Stage | Kc [coeff] | ETc [mm/day] | ETc [mm/dec] | Eff rain [mm/dec] | Irr. Req. [mm/dec] |
|---|---|---|---|---|---|---|---|
| **Apr** | 1 | Init | 0.70 | 1.61 | 16.1 | 22.7 | 0.0 |
| **Apr** | 2 | Init | 0.70 | 1.77 | 17.7 | 26.9 | 0.0 |
| **Apr** | 3 | Init | 0.70 | 2.02 | 20.2 | 23.3 | 0.0 |
| **May** | 1 | Init | 0.70 | 2.27 | 22.7 | 17.4 | 5.3 |
| **May** | 2 | Deve | 0.73 | 2.63 | 26.3 | 14.0 | 12.4 |
| **May** | 3 | Deve | 0.79 | 3.06 | 33.6 | 16.8 | 16.8 |
| **Jun** | 1 | Deve | 0.85 | 3.51 | 35.1 | 21.8 | 13.4 |
| **Jun** | 2 | Deve | 0.91 | 3.99 | 39.9 | 24.7 | 15.2 |
| **Jun** | 3 | Deve | 0.97 | 4.45 | 44.5 | 20.7 | 23.9 |
| **Jul** | 1 | Mid | 1.03 | 5.00 | 50.0 | 14.3 | 35.7 |
| **Jul** | 2 | Mid | 1.05 | 5.36 | 53.6 | 10.3 | 43.3 |
| **Jul** | 3 | Mid | 1.05 | 5.16 | 56.8 | 13.4 | 43.4 |
| **Aug** | 1 | Mid | 1.05 | 5.00 | 50.0 | 17.3 | 32.7 |
| **Aug** | 2 | Mid | 1.05 | 4.87 | 48.7 | 19.6 | 29.1 |
| **Aug** | 3 | Late | 1.05 | 4.28 | 47.1 | 21.7 | 25.4 |
| **Sep** | 1 | Late | 0.99 | 3.49 | 34.9 | 23.9 | 11.1 |
| **Sep** | 2 | Late | 0.95 | 2.87 | 5.7 | 5.2 | 5.7 |
| | | | | | | | |
| Total | | | | | **603.1** | **313.8** | **313.4** |

*Table 9. Water requirement per average year for tomato.*

| Month | Decade | Stage | Kc [coeff] | ETc [mm/day] | ETc [mm/dec] | Eff rain [mm/dec] | Irr. Req. [mm/dec] |
|---|---|---|---|---|---|---|---|
| **Apr** | 1 | Init | 0.60 | 1.38 | 13.8 | 30.9 | 0.0 |
| **Apr** | 2 | Init | 0.60 | 1.52 | 15.2 | 31.5 | 0.0 |
| **Apr** | 3 | Init | 0.60 | 1.73 | 17.3 | 30.0 | 0.0 |
| **May** | 1 | Deve | 0.68 | 2.19 | 21.9 | 27.7 | 0.0 |
| **May** | 2 | Deve | 0.81 | 2.92 | 29.2 | 26.1 | 3.1 |
| **May** | 3 | Deve | 0.96 | 3.69 | 40.6 | 27.6 | 12.9 |
| **Jun** | 1 | Mid | 1.10 | 4.52 | 45.2 | 31.0 | 14.3 |
| **Jun** | 2 | Mid | 1.15 | 5.03 | 50.3 | 32.9 | 17.4 |
| **Jun** | 3 | Mid | 1.15 | 5.27 | 52.7 | 28.3 | 24.4 |
| **Jul** | 1 | Mid | 1.15 | 5.59 | 55.9 | 20.8 | 35.1 |
| **Jul** | 2 | Mid | 1.15 | 5.87 | 58.7 | 15.8 | 42.9 |
| **Jul** | 3 | Late | 1.13 | 5.55 | 61.1 | 20.7 | 40.4 |
| **Aug** | 1 | Late | 1.05 | 4.98 | 49.8 | 26.8 | 23.0 |
| **Aug** | 2 | Late | 0.96 | 4.47 | 44.7 | 30.6 | 14.0 |
| **Aug** | 3 | Late | 0.91 | 3.72 | 11.2 | 9.2 | 0.0 |
| | | | | | | | |
| Total | | | | | **567.5** | **389.8** | **227.7** |

*Table 10. Water requirement per dry year for tomato.*

| Month | Decade | Stage | Kc [coeff] | ETc [mm/day] | ETc [mm/dec] | Eff rain [mm/dec] | Irr. Req. [mm/dec] |
|---|---|---|---|---|---|---|---|
| **Apr** | 1 | Init | 0.60 | 1.38 | 13.8 | 22.7 | 0.0 |
| **Apr** | 2 | Init | 0.60 | 1.52 | 15.2 | 26.9 | 0.0 |
| **Apr** | 3 | Init | 0.60 | 1.73 | 17.3 | 23.3 | 0.0 |
| **May** | 1 | Deve | 0.68 | 2.19 | 21.9 | 17.4 | 4.5 |
| **May** | 2 | Deve | 0.81 | 2.92 | 29.2 | 14.0 | 15.3 |
| **May** | 3 | Deve | 0.96 | 3.69 | 40.6 | 16.8 | 23.8 |
| **Jun** | 1 | Mid | 1.10 | 4.52 | 45.2 | 21.8 | 23.5 |
| **Jun** | 2 | Mid | 1.15 | 5.03 | 50.3 | 24.7 | 25.6 |
| **Jun** | 3 | Mid | 1.15 | 5.27 | 52.7 | 20.7 | 32.0 |
| **Jul** | 1 | Mid | 1.15 | 5.59 | 55.9 | 14.3 | 41.6 |
| **Jul** | 2 | Mid | 1.15 | 5.87 | 58.7 | 10.3 | 48.4 |
| **Jul** | 3 | Late | 1.13 | 5.55 | 61.1 | 13.4 | 47.7 |
| **Aug** | 1 | Late | 1.05 | 4.98 | 49.8 | 17.3 | 32.5 |
| **Aug** | 2 | Late | 0.96 | 4.47 | 44.7 | 19.6 | 25.0 |
| **Aug** | 3 | Late | 0.91 | 3.72 | 11.2 | 5.9 | 0.3 |
| | | | | | | | |
| Total | | | | | **567.5** | **268.9** | **320.2** |

*Table 11. Water requirement per average year for pepper.*

| Month | Decade | Stage | Kc [coeff] | ETc [mm/day] | ETc [mm/dec] | Eff rain [mm/dec] | Irr. Req. [mm/dec] |
|---|---|---|---|---|---|---|---|
| **May** | 1 | Init | 0.60 | 1.94 | 19.4 | 27.7 | 0.0 |
| **May** | 2 | Init | 0.60 | 2.16 | 21.6 | 26.1 | 0.0 |
| **May** | 3 | Deve | 0.60 | 2.32 | 25.5 | 27.6 | 0.0 |
| **Jun** | 1 | Deve | 0.68 | 2.81 | 28.1 | 31.0 | 0.0 |
| **Jun** | 2 | Deve | 0.81 | 3.55 | 35.5 | 32.9 | 2.6 |
| **Jun** | 3 | Deve | 0.94 | 4.31 | 43.1 | 28.3 | 14.8 |
| **Jul** | 1 | Mid | 1.04 | 5.07 | 50.7 | 20.8 | 29.9 |
| **Jul** | 2 | Mid | 1.05 | 5.36 | 53.6 | 15.8 | 37.8 |
| **Jul** | 3 | Mid | 1.05 | 5.16 | 56.8 | 20.7 | 36.1 |
| **Aug** | 1 | Mid | 1.05 | 5.00 | 50.0 | 26.8 | 23.2 |
| **Aug** | 2 | Late | 1.03 | 4.77 | 47.7 | 30.6 | 17.1 |
| **Aug** | 3 | Late | 0.95 | 3.90 | 42.9 | 33.8 | 9.1 |
| **Sep** | 1 | Late | 0.90 | 3.18 | 6.4 | 7.5 | 6.4 |
| | | | | | | | |
| Total | | | | | **481.3** | **329.5** | **177.0** |

*Table 12. Water requirement per dry year for pepper.*

| Month | Decade | Stage | Kc [coeff] | ETc [mm/day] | ETc [mm/dec] | Eff rain [mm/dec] | Irr. Req. [mm/dec] |
|---|---|---|---|---|---|---|---|
| **May** | 1 | Init | 0.60 | 1.94 | 19.4 | 17.4 | 2.0 |
| **May** | 2 | Init | 0.60 | 2.16 | 21.6 | 14.0 | 7.6 |
| **May** | 3 | Deve | 0.60 | 2.32 | 25.5 | 16.8 | 8.7 |
| **Jun** | 1 | Deve | 0.68 | 2.81 | 28.1 | 21.8 | 6.3 |
| **Jun** | 2 | Deve | 0.81 | 3.55 | 35.5 | 24.7 | 10.8 |
| **Jun** | 3 | Deve | 0.94 | 4.31 | 43.1 | 20.7 | 22.5 |
| **Jul** | 1 | Mid | 1.04 | 5.07 | 50.7 | 14.3 | 36.3 |
| **Jul** | 2 | Mid | 1.05 | 5.36 | 53.6 | 10.3 | 43.3 |
| **Jul** | 3 | Mid | 1.05 | 5.16 | 56.8 | 13.4 | 43.4 |
| **Aug** | 1 | Mid | 1.05 | 5.00 | 50.0 | 17.3 | 32.7 |
| **Aug** | 2 | Late | 1.03 | 4.77 | 47.7 | 19.6 | 28.1 |
| **Aug** | 3 | Late | 0.95 | 3.90 | 42.9 | 21.7 | 21.2 |
| **Sep** | 1 | Late | 0.90 | 3.18 | 6.4 | 4.8 | 6.4 |
| | | | | | | | |
| Total | | | | | **481.3** | **216.7** | **269.4** |

***Table 13.*** *Water requirement per average year for cucumber.*

| Month | Decade | Stage | Kc [coeff] | ETc [mm/day] | ETc [mm/dec] | Eff rain [mm/dec] | Irr. Req. [mm/dec] |
|---|---|---|---|---|---|---|---|
| **Jun** | 1 | Init | 0.60 | 2.47 | 24.7 | 31.0 | 0.0 |
| **Jun** | 2 | Init | 0.60 | 2.62 | 26.2 | 32.9 | 0.0 |
| **Jun** | 3 | Deve | 0.67 | 3.09 | 30.9 | 28.3 | 2.6 |
| **Jul** | 1 | Deve | 0.81 | 3.92 | 39.2 | 20.8 | 18.4 |
| **Jul** | 2 | Deve | 0.94 | 4.80 | 48.0 | 15.8 | 32.2 |
| **Jul** | 3 | Mid | 1.00 | 4.92 | 54.1 | 20.7 | 33.4 |
| **Aug** | 1 | Mid | 1.00 | 4.76 | 47.6 | 26.8 | 20.9 |
| **Aug** | 2 | Mid | 1.00 | 4.64 | 46.4 | 30.6 | 15.8 |
| **Aug** | 3 | Late | 1.00 | 4.08 | 44.8 | 33.8 | 11.0 |
| **Sep** | 1 | Late | 0.87 | 3.08 | 30.8 | 37.3 | 0.0 |
| **Sep** | 2 | Late | 0.77 | 2.30 | 6.9 | 12.2 | 0.0 |
| | | | | | | | |
| Total | | | | | **399.6** | **290.1** | **134.3** |

***Table 14.*** *Water requirement per dry year for cucumber.*

| Month | Decade | Stage | Kc [coeff] | ETc [mm/day] | ETc [mm/dec] | Eff rain [mm/dec] | Irr. Req. [mm/dec] |
|---|---|---|---|---|---|---|---|
| **Jun** | 1 | Init | 0.60 | 2.47 | 24.7 | 21.8 | 2.9 |
| **Jun** | 2 | Init | 0.60 | 2.62 | 26.2 | 24.7 | 1.6 |
| **Jun** | 3 | Deve | 0.67 | 3.09 | 30.9 | 20.7 | 10.2 |
| **Jul** | 1 | Deve | 0.81 | 3.92 | 39.2 | 14.3 | 24.9 |
| **Jul** | 2 | Deve | 0.94 | 4.80 | 48.0 | 10.3 | 37.7 |
| **Jul** | 3 | Mid | 1.00 | 4.92 | 54.1 | 13.4 | 40.7 |
| **Aug** | 1 | Mid | 1.00 | 4.76 | 47.6 | 17.3 | 30.3 |
| **Aug** | 2 | Mid | 1.00 | 4.64 | 46.4 | 19.6 | 26.8 |
| **Aug** | 3 | Late | 1.00 | 4.08 | 44.8 | 21.7 | 23.1 |
| **Sep** | 1 | Late | 0.87 | 3.08 | 30.8 | 23.9 | 6.9 |
| **Sep** | 2 | Late | 0.77 | 2.30 | 6.9 | 7.8 | 0.0 |
| | | | | | | | |
| Total | | | | | **399.6** | **195.4** | **205.1** |

***Table 15.*** *Water requirement per average year for onion.*

| Month | Decade | Stage | Kc [coeff] | ETc [mm/day] | ETc [mm/dec] | Eff rain [mm/dec] | Irr. Req. [mm/dec] |
|---|---|---|---|---|---|---|---|
| **Mar** | 1 | Init | 0.70 | 1.16 | 11.6 | 29.6 | 0.0 |
| **Mar** | 2 | Deve | 0.72 | 1.33 | 13.3 | 29.8 | 0.0 |
| **Mar** | 3 | Deve | 0.85 | 1.77 | 19.5 | 30.1 | 0.0 |
| **Apr** | 1 | Mid | 1.00 | 2.30 | 23.0 | 30.9 | 0.0 |
| **Apr** | 2 | Mid | 1.05 | 2.66 | 26.6 | 31.5 | 0.0 |
| **Apr** | 3 | Mid | 1.05 | 3.03 | 30.3 | 30.0 | 0.3 |
| **May** | 1 | Mid | 1.05 | 3.40 | 34.0 | 27.7 | 6.3 |
| **May** | 2 | Mid | 1.05 | 3.77 | 37.7 | 26.1 | 11.6 |
| **May** | 3 | Mid | 1.05 | 4.05 | 44.5 | 27.6 | 16.9 |
| **Jun** | 1 | Mid | 1.05 | 4.32 | 43.2 | 31.0 | 12.2 |
| **Jun** | 2 | Late | 1.05 | 4.58 | 45.8 | 32.9 | 12.9 |
| **Jun** | 3 | Late | 0.99 | 4.55 | 45.5 | 28.3 | 17.3 |
| **Jul** | 1 | Late | 0.92 | 4.47 | 44.7 | 20.8 | 23.9 |
| **Jul** | 2 | Late | 0.84 | 4.31 | 43.1 | 15.8 | 27.3 |
| **Jul** | 3 | Late | 0.78 | 3.82 | 30.5 | 15.0 | 9.9 |
| | | | | | | | |
| Total | | | | | **493.3** | **407.0** | **138.5** |

***Table 16.*** *Water requirement per dry year for onion.*

| Month | Decade | Stage | Kc [coeff] | ETc [mm/day] | ETc [mm/dec] | Eff rain [mm/dec] | Irr. Req. [mm/dec] |
|---|---|---|---|---|---|---|---|
| **Mar** | 1 | Init | 0.70 | 1.16 | 11.6 | 13.6 | 0.0 |
| **Mar** | 2 | Deve | 0.72 | 1.33 | 13.3 | 12.6 | 0.7 |
| **Mar** | 3 | Deve | 0.85 | 1.77 | 19.5 | 16.5 | 3.0 |
| **Apr** | 1 | Mid | 1.00 | 2.30 | 23.0 | 22.7 | 0.4 |
| **Apr** | 2 | Mid | 1.05 | 2.66 | 26.6 | 26.9 | 0.0 |
| **Apr** | 3 | Mid | 1.05 | 3.03 | 30.3 | 23.3 | 7.0 |
| **May** | 1 | Mid | 1.05 | 3.40 | 34.0 | 17.4 | 16.6 |
| **May** | 2 | Mid | 1.05 | 3.77 | 37.7 | 14.0 | 23.8 |
| **May** | 3 | Mid | 1.05 | 4.05 | 44.5 | 16.8 | 27.7 |
| **Jun** | 1 | Mid | 1.05 | 4.32 | 43.2 | 21.8 | 21.4 |
| **Jun** | 2 | Late | 1.05 | 4.58 | 45.8 | 24.7 | 21.1 |
| **Jun** | 3 | Late | 0.99 | 4.55 | 45.5 | 20.7 | 24.9 |
| **Jul** | 1 | Late | 0.92 | 4.47 | 44.7 | 14.3 | 30.3 |
| **Jul** | 2 | Late | 0.84 | 4.31 | 43.1 | 10.3 | 32.8 |
| **Jul** | 3 | Late | 0.78 | 3.82 | 30.5 | 9.7 | 17.1 |
| | | | | | | | |
| Total | | | | | **493.3** | **265.1** | **226.9** |

*__Table 17.__ Water requirement per average year for lettuce.*

| Month | Decade | Stage | Kc [coeff] | ETc [mm/day] | ETc [mm/dec] | Eff rain [mm/dec] | Irr. Req. [mm/dec] |
|---|---|---|---|---|---|---|---|
| **Jun** | 1 | Init | 0.70 | 2.88 | 28.8 | 31.0 | 0.0 |
| **Jun** | 2 | Init | 0.70 | 3.06 | 30.6 | 32.9 | 0.0 |
| **Jun** | 3 | Deve | 0.76 | 3.46 | 34.6 | 28.3 | 6.3 |
| **Jul** | 1 | Deve | 0.85 | 4.16 | 41.6 | 20.8 | 20.8 |
| **Jul** | 2 | Deve | 0.95 | 4.88 | 48.8 | 15.8 | 33.0 |
| **Jul** | 3 | Mid | 1.00 | 4.92 | 54.1 | 20.7 | 33.4 |
| **Aug** | 1 | Late | 0.99 | 4.71 | 47.1 | 26.8 | 20.4 |
| **Aug** | 2 | Late | 0.96 | 4.44 | 17.8 | 12.3 | 2.5 |
| | | | | | | | |
| Total | | | | | **303.3** | **188.4** | **116.3** |

*__Table 18.__ Water requirement per dry year for lettuce.*

| Month | Decade | Stage | Kc [coeff] | ETc [mm/day] | ETc [mm/dec] | Eff rain [mm/dec] | Irr. Req. [mm/dec] |
|---|---|---|---|---|---|---|---|
| **Jun** | 1 | Init | 0.70 | 2.88 | 28.8 | 21.8 | 7.0 |
| **Jun** | 2 | Init | 0.70 | 3.06 | 30.6 | 24.7 | 5.9 |
| **Jun** | 3 | Deve | 0.76 | 3.46 | 34.6 | 20.7 | 13.9 |
| **Jul** | 1 | Deve | 0.85 | 4.16 | 41.6 | 14.3 | 27.2 |
| **Jul** | 2 | Deve | 0.95 | 4.88 | 48.8 | 10.3 | 38.5 |
| **Jul** | 3 | Mid | 1.00 | 4.92 | 54.1 | 13.4 | 40.7 |
| **Aug** | 1 | Late | 0.99 | 4.71 | 47.1 | 17.3 | 29.8 |
| **Aug** | 2 | Late | 0.96 | 4.44 | 17.8 | 7.8 | 8.0 |
| | | | | | | | |
| Total | | | | | **303.3** | **130.3** | **171.1** |

*__Table 19.__ Water requirement per average year for watermelon.*

| Month | Decade | Stage | Kc [coeff] | ETc [mm/day] | ETc [mm/dec] | Eff rain [mm/dec] | Irr. Req. [mm/dec] |
|---|---|---|---|---|---|---|---|
| **May** | 1 | Init | 0.40 | 1.30 | 13.0 | 27.7 | 0.0 |
| **May** | 2 | Init | 0.40 | 1.44 | 14.4 | 26.1 | 0.0 |
| **May** | 3 | Deve | 0.52 | 2.00 | 22.0 | 27.6 | 0.0 |
| **Jun** | 1 | Deve | 0.73 | 3.00 | 30.0 | 31.0 | 0.0 |
| **Jun** | 2 | Mid | 0.93 | 4.06 | 40.6 | 32.9 | 7.7 |
| **Jun** | 3 | Mid | 1.00 | 4.58 | 45.8 | 28.3 | 17.5 |
| **Jul** | 1 | Mid | 1.00 | 4.86 | 48.6 | 20.8 | 27.8 |
| **Jul** | 2 | Late | 1.00 | 5.10 | 51.0 | 15.8 | 35.2 |
| **Jul** | 3 | Late | 0.94 | 4.63 | 50.9 | 20.7 | 30.3 |
| **Aug** | 1 | Late | 0.85 | 4.07 | 40.7 | 26.8 | 13.9 |
| **Aug** | 2 | Late | 0.78 | 3.62 | 28.9 | 24.5 | 0.0 |
| | | | | | | | |
| Total | | | | | **385.9** | **282.0** | **132.4** |

***Table 20.*** *Water requirement per dry year for watermelon.*

| Month | Decade | Stage | Kc [coeff] | ETc [mm/day] | ETc [mm/dec] | Eff rain [mm/dec] | Irr. Req. [mm/dec] |
|---|---|---|---|---|---|---|---|
| **May** | 1 | Init | 0.40 | 1.30 | 13.0 | 17.4 | 0.0 |
| **May** | 2 | Init | 0.40 | 1.44 | 14.4 | 14.0 | 0.4 |
| **May** | 3 | Deve | 0.52 | 2.00 | 22.0 | 16.8 | 5.3 |
| **Jun** | 1 | Deve | 0.73 | 3.00 | 30.0 | 21.8 | 8.2 |
| **Jun** | 2 | Mid | 0.93 | 4.06 | 40.6 | 24.7 | 15.9 |
| **Jun** | 3 | Mid | 1.00 | 4.58 | 45.8 | 20.7 | 25.2 |
| **Jul** | 1 | Mid | 1.00 | 4.86 | 48.6 | 14.3 | 34.3 |
| **Jul** | 2 | Late | 1.00 | 5.10 | 51.0 | 10.3 | 40.7 |
| **Jul** | 3 | Late | 0.94 | 4.63 | 50.9 | 13.4 | 37.5 |
| **Aug** | 1 | Late | 0.85 | 4.07 | 40.7 | 17.3 | 23.4 |
| **Aug** | 2 | Late | 0.78 | 3.62 | 28.9 | 15.7 | 9.3 |
| | | | | | | | |
| **Total** | | | | | **385.9** | **186.2** | **200.2** |

## 6.2.4. Annual amounts of irrigation water need

Water stress occurs when the demand for water exceeds the available amount during a certain period or when poor quality restricts its use. For optimum crop development available amount of crop water must be greater than amount of water when water stress occurs.

Crop water can be supplied to the crops in various ways:
· by rainfall
· by irrigation
· by a combination of irrigation and rainfall

In cases where all the water needed for optimal growth of the crop is provided by rainfall, irrigation is not required, and the Irrigation water need (IN) equals zero:

$$IN = 0 \quad (6)$$

In cases where there is no rainfall at all during the growing season, all water must be supplied by irrigation. Consequently, the irrigation water needs (IN) equals the crop water need (ET crop):

$$IN = ETcrop \quad (7)$$

In most cases as it is the case of this diploma thesis, part of the crop water need is supplied by rainfall and the remaining part by irrigation. In such cases the irrigation water needs (IN) is the difference between the crop water need (ET crop) and that part of the rainfall which is effectively used by the plants ($P_{eff}$). In formula:

$$IN = ETcrop - P_{eff} \quad (8)$$

According to the formula (8), annual amounts of water need per average and dry year are shown in the table 21., and table 22. Net irrigation water need is the quantity of water necessary for crop growth. It is expressed in millimeters per year or in $\mathrm{m}^3$/ha per year (1 mm = 10 $\mathrm{m}^3$/ha). Multiplying irrigation water need by the area that is suitable for irrigation, gives the total water requirement for that area.

***Table 21.*** *Annual amounts of irrigation water need per average year.*

| **Crops** | **Irrigated surface [ha]** | **Irrigation water need $[\mathrm{m}^3/\mathrm{ha}]$** | **Net irrigation water needs $[\mathrm{m}^3]$** |
|---|---|---|---|
| **potato** | 18,6 | 1073 | 19. 957, 00 |
| **cabbage** | 2,5 | 1433 | 3. 582, 52 |
| **tomato** | 1,9 | 1777 | 3. 376, 30 |
| **pepper** | 2,9 | 1518 | 4. 402, 20 |
| **cucumber** | 1,1 | 1095 | 1. 204, 50 |
| **onion** | 3,4 | 863 | 2. 934, 20 |
| **lettuce** | 1,2 | 1149 | 1. 378, 80 |
| **watermelon** | 0,5 | 1039 | 519, 50 |
| Total | 32,1 | 9 947 | 37. 355, 02 |

***Table 22.*** *Annual amounts of irrigation water need per dry year.*

| **Crops** | **Irrigated surface [ha]** | **Irrigation water need $[\mathrm{m}^3/\mathrm{ha}]$** | **Net irrigation water needs $[\mathrm{m}^3]$** |
|---|---|---|---|
| **potato** | 18,6 | 2282 | 42.445, 20 |
| **cabbage** | 2,5 | 2893 | 7.232, 50 |
| **tomato** | 1,9 | 2986 | 5.673, 40 |
| **pepper** | 2,9 | 2646 | 7.673, 40 |
| **cucumber** | 1,1 | 2042 | 2.246, 20 |
| **onion** | 3,4 | 2282 | 7.758, 80 |
| **lettuce** | 1,2 | 1730 | 2.076,00 |
| **watermelon** | 0,5 | 1997 | 998,50 |
| Total | 32,1 | 18 858 | 76. 104, 00 |

Calculated amounts of irrigation water requirements are the amount that plant need on site. Information on irrigation efficiency is necessary to be able to transform net irrigation water need into gross irrigation water need, which is the quantity of water to be applied in reality, taking into account water losses. Assumed losses are 10% for pipelines and 10% for irrigation equipment. Taking this into account, total annual gross amounts of irrigation water need are 44. 826, 03 $\mathrm{m}^3$ for an average year, and 91. 324, 80 $\mathrm{m}^3$ for dry year.

### 6.2.5. Hydro-module calculation

Hydro-module is an important element for designing irrigation systems. The hydro-module represents the amount of water that must be brought to the soil in unit time per unit area (l/s/ha). Hydro-module was determined using the CROPWAT program. With the help of irrigation scheduling, water will be applied at the right time and in the right quantity in order to optimize the production of crops. The Field Water Supply (Hydro-module) for one hectare is calculated according to formula:

$$FWS = 1\ hectare\ \times\ Net\ Irr.\ required \times (100/Irrigation\ efficiency) \qquad (9)$$

where Irrigation efficiency is 70% according to CROPWAT 8.0. default setting.

Figures 15.-22. represent irrigation scheduling graphs per dry year for eight crops in this diploma thesis, where green line (TAM) is the total available moisture or the total amount of water available to the crop. Brown line (RAM) is the readily available water or the portion of (TAM) that the plant can get from the root zone without facing water stress. Tables 23.-30. illustrate the field crop irrigation schedules (only the biggest month values) for eight crops per dry year in this diploma thesis.

***Table 23.*** *Irrigation scheduling per dry year for potato.*

| Date | Day | Stage | Rain [mm] | Ks [fract.] | Eta [%] | Depl. [%] | Net Irr. [mm] | Deficit [mm] | Loss [mm] | Gr. Irr. [mm] | FWS [l/s/ha] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 Apr | 1 | Init | 0.0 | 0.77 | 77 | 60 | 5.5 | 0.0 | 0.0 | 7.8 | **0.90** |
| 30 Apr | 30 | Init | 0.0 | 1.00 | 100 | 44 | 5.8 | 0.0 | 0.0 | 8.3 | **0.19** |
| 22 May | 52 | Dev | 0.0 | 1.00 | 100 | 43 | 6.9 | 0.0 | 0.0 | 9.9 | **0.57** |
| 25 Jun | 86 | Mid | 0.0 | 1.00 | 100 | 53 | 9.5 | 0.0 | 0.0 | 13.5 | **0.78** |
| 15 Jul | 106 | Mid | 0.0 | 1.00 | 100 | 59 | 10.6 | 0.0 | 0.0 | 15.1 | **0.87** |
| 10 Aug | 132 | End | 0.0 | 1.00 | 100 | 46 | 8.3 | 0.0 | 0.0 | 11.8 | **0.68** |
| 23 Aug | End | End | 0.0 | 1.00 | 0 | 18 | | | | | |

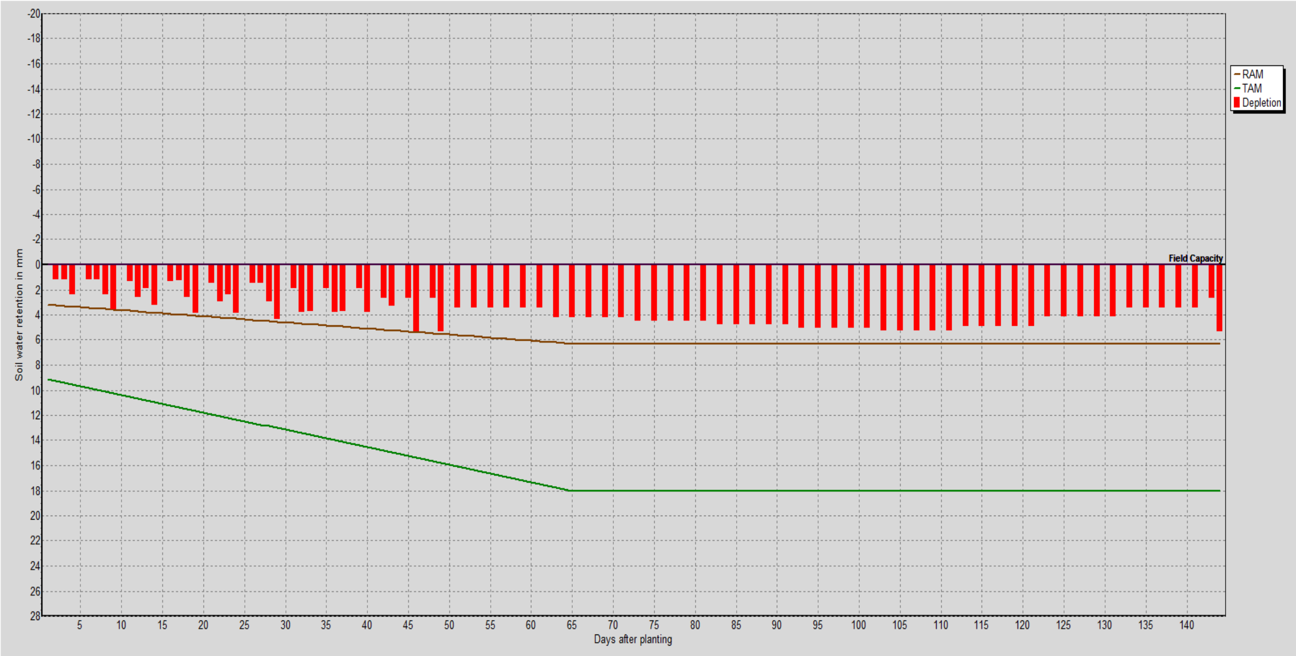


***Figure 15***. *Irrigation scheduling graph per dry year for potato.*

***Table 24.*** *Irrigation scheduling per dry year for cabbage.*

| Date | Day | Stage | Rain [mm] | Ks [fract.] | Eta [%] | Depl. [%] | Net Irr. [mm] | Deficit [mm] | Loss [mm] | Gr. Irr. [mm] | FWS [l/s/ha] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 Apr | 1 | Init | 0.0 | 0.91 | 91 | 66 | 6.0 | 0.0 | 0.0 | 8.6 | **1.00** |
| 25 Apr | 25 | Init | 0.0 | 1.00 | 100 | 51 | 6.1 | 0.0 | 0.0 | 8.7 | **0.33** |
| 25 May | 55 | Dev | 0.0 | 1.00 | 100 | 59 | 9.2 | 0.0 | 0.0 | 13.1 | **0.51** |
| 28 Jun | 89 | Dev | 0.0 | 1.00 | 100 | 45 | 8.9 | 0.0 | 0.0 | 12.7 | **0.74** |
| 18 Jul | 109 | Mid | 0.0 | 1.00 | 100 | 51 | 10.7 | 0.0 | 0.0 | 15.3 | **0.89** |
| 1 Aug | 123 | Mid | 0.0 | 1.00 | 100 | 48 | 10.2 | 0.0 | 0.0 | 14.5 | **0.84** |
| 1 Sep | 154 | End | 0.0 | 1.00 | 100 | 57 | 12.1 | 0.0 | 0.0 | 17.2 | **0.66** |
| 12 Sep | End | End | 0.0 | 1.00 | 0 | 30 | | | | | |

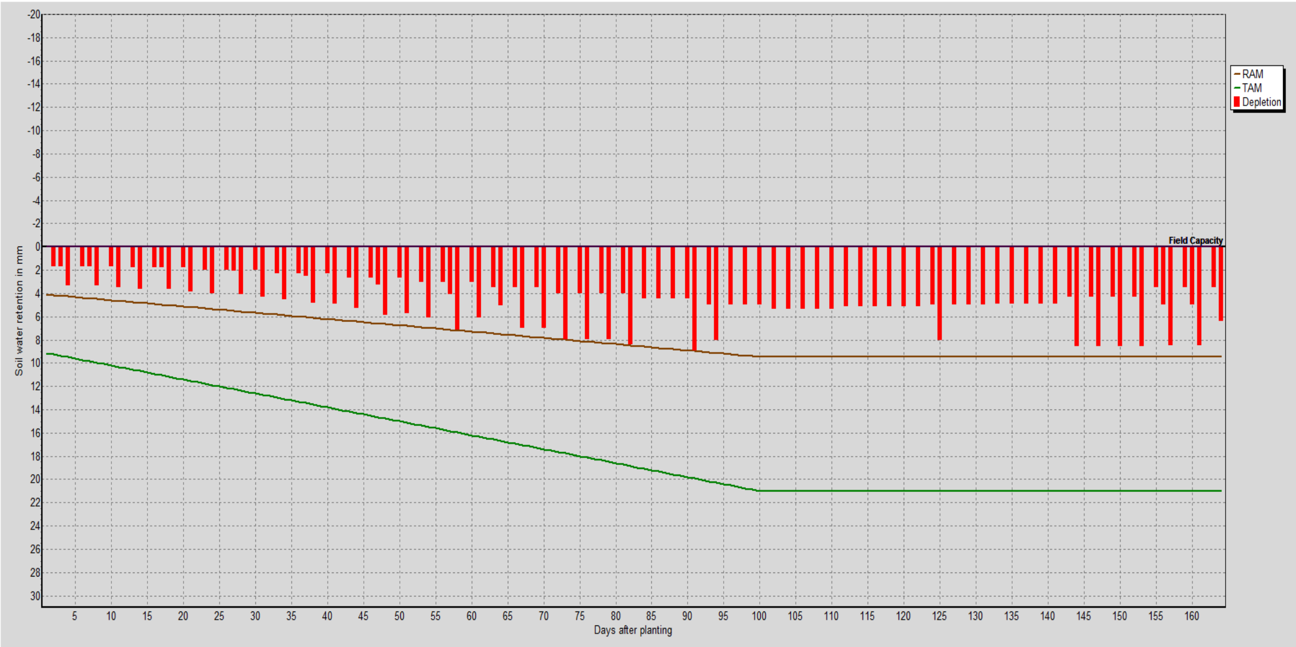


***Figure 16.*** *Irrigation scheduling graph per dry year for cabbage.*

***Table 25****. Irrigation scheduling per dry year for tomato.*

| Date | Day | Stage | Rain [mm] | Ks [fract.] | Eta [%] | Depl. [%] | Net Irr. [mm] | Deficit [mm] | Loss [mm] | Gr. Irr. [mm] | FWS [l/s/ha] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1 Apr** | 1 | Init | 0.0 | 0.83 | 83 | 63 | 5.7 | 0.0 | 0.0 | 8.2 | **0.95** |
| **15 Apr** | 15 | Init | 0.0 | 1.00 | 100 | 40 | 4.7 | 0.0 | 0.0 | 6.7 | **0.26** |
| **24 May** | 54 | Dev | 0.0 | 1.00 | 100 | 40 | 7.4 | 0.0 | 0.0 | 10.5 | **0.61** |
| **28 Jun** | 89 | Mid | 0.0 | 1.00 | 100 | 50 | 10.5 | 0.0 | 0.0 | 15.1 | **0.87** |
| **12 Jul** | 103 | Mid | 0.0 | 1.00 | 100 | 56 | 11.7 | 0.0 | 0.0 | 16.8 | **0.97** |
| **1 Aug** | 123 | End | 0.0 | 1.00 | 100 | 50 | 10.5 | 0.0 | 0.0 | 15.0 | **0.87** |
| **20 Aug** | 142 | End | 0.0 | 1.00 | 100 | 43 | 8.9 | 0.0 | 0.0 | 12.8 | **0.74** |
| **23 Aug** | End | End | 12.4 | 1.00 | 100 | 26 | | | | | |

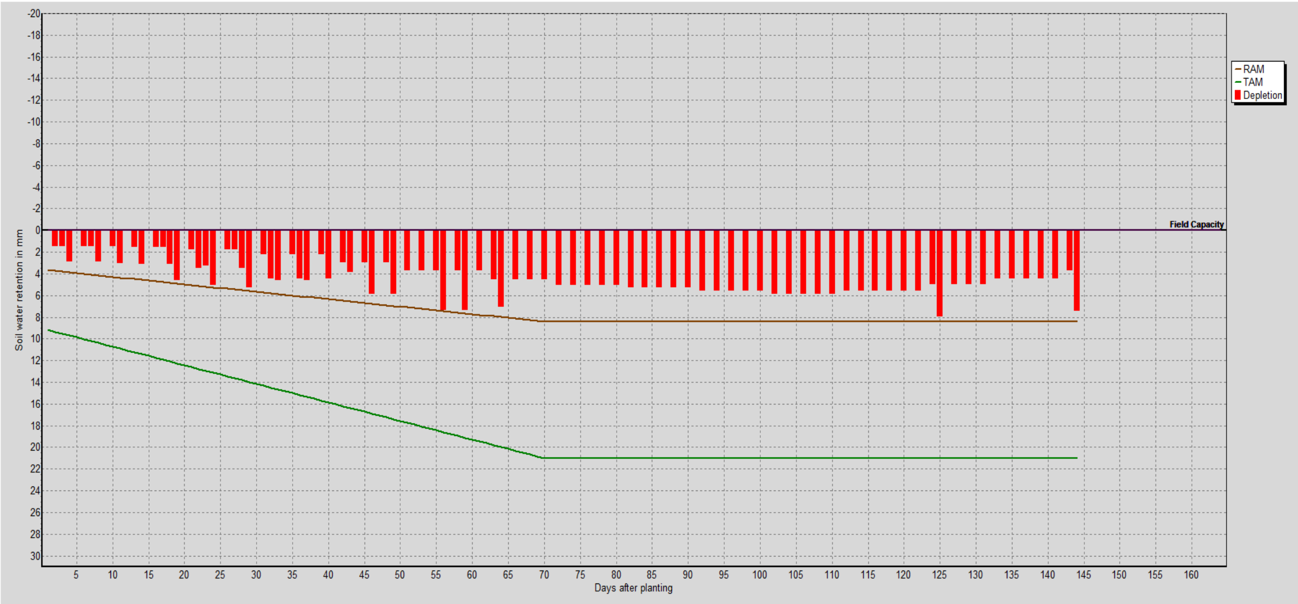


***Figure 17.*** *Irrigation scheduling graph per dry year for tomato.*

***Table 26****. Irrigation scheduling per dry year for pepper.*

| Date | Day | Stage | Rain [mm] | Ks [fract.] | Eta [%] | Depl. [%] | Net Irr. [mm] | Deficit [mm] | Loss [mm] | Gr. Irr. [mm] | FWS [l/s/ha] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1 May** | 1 | Init | 0.0 | 0.71 | 71 | 65 | 6.0 | 0.0 | 0.0 | 8.5 | **0.99** |
| **26 Jun** | 57 | Dev | 0.0 | 1.00 | 100 | 44 | 8.6 | 0.0 | 0.0 | 12.3 | **0.71** |
| **20 Jul** | 81 | Mid | 0.0 | 1.00 | 100 | 51 | 10.7 | 0.0 | 0.0 | 15.3 | **0.89** |
| **1 Aug** | 93 | Mid | 0.0 | 1.00 | 100 | 48 | 10.2 | 0.0 | 0.0 | 14.5 | **0.84** |
| **5 Aug** | 97 | Mid | 0.0 | 1.00 | 100 | 48 | 10.0 | 0.0 | 0.0 | 14.3 | **0.83** |
| **13 Aug** | 105 | Mid | 10.9 | 1.00 | 100 | 36 | 7.5 | 0.0 | 0.0 | 10.8 | **0.62** |
| **15 Aug** | 107 | End | 0.0 | 1.00 | 100 | 45 | 9.5 | 0.0 | 0.0 | 13.6 | **0.79** |
| **30 Aug** | 122 | End | 0.0 | 1.00 | 100 | 37 | 7.8 | 0.0 | 0.0 | 11.1 | **0.64** |
| **1 Sep** | 124 | End | 0.0 | 1.00 | 100 | 34 | 7.1 | 0.0 | 0.0 | 10.1 | **0.59** |
| **2 Sep** | End | End | 9.5 | 1.00 | 0 | 0 | | | | | |

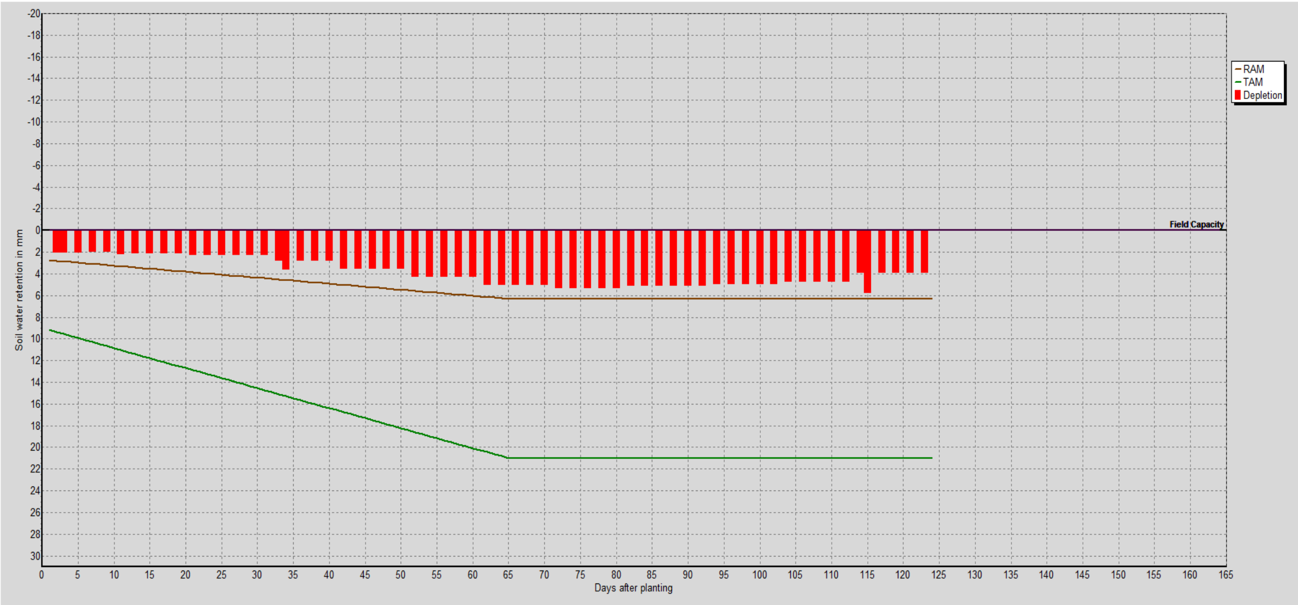


***Figure 18.*** *Irrigation scheduling graph per dry year for pepper.*

***Table 27.*** *Irrigation scheduling per dry year for cucumber.*

| Date | Day | Stage | Rain | Ks | Eta | Depl. | Net Irr. | Deficit | Loss | Gr. Irr. | FWS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | [mm] | [fract.] | [%] | [%] | [mm] | [mm] | [mm] | [mm] | [l/s/ha] |
| **1 Jun** | 1 | Init | 0.0 | 1.00 | 100 | 77 | 7.1 | 0.0 | 0.0 | 10.1 | **1.17** |
| **4 Jun** | 4 | Init | 0.0 | 1.00 | 100 | 58 | 5.8 | 0.0 | 0.0 | 8.2 | **0.32** |
| **22 Jun** | 22 | Dev | 0.0 | 1.00 | 100 | 63 | 9.0 | 0.0 | 0.0 | 12.8 | **0.49** |
| **25 Jun** | 25 | Dev | 0.0 | 1.00 | 100 | 62 | 9.3 | 0.0 | 0.0 | 13.2 | **0.51** |
| **29 Jun** | 29 | Dev | 0.0 | 1.00 | 100 | 65 | 10.3 | 0.0 | 0.0 | 14.8 | **0.43** |
| **17 Jul** | 47 | Dev | 5.3 | 1.00 | 100 | 61 | 12.4 | 0.0 | 0.0 | 17.7 | **0.68** |
| **20 Jul** | 50 | Dev | 0.0 | 1.00 | 100 | 69 | 14.4 | 0.0 | 0.0 | 20.6 | **0.79** |
| **26 Jul** | 56 | Mid | 0.0 | 1.00 | 100 | 70 | 14.8 | 0.0 | 0.0 | 21.1 | **0.81** |
| **1 Aug** | 62 | Mid | 0.0 | 1.00 | 100 | 70 | 14.6 | 0.0 | 0.0 | 20.9 | **0.80** |
| **16 Aug** | 77 | Mid | 0.0 | 1.00 | 100 | 66 | 13.9 | 0.0 | 0.0 | 19.9 | **0.77** |
| **22 Aug** | 83 | Mid | 0.0 | 1.00 | 100 | 61 | 12.8 | 0.0 | 0.0 | 18.3 | **0.71** |
| **1 Sep** | 93 | End | 0.0 | 1.00 | 100 | 53 | 11.2 | 0.0 | 0.0 | 16.0 | **0.62** |
| **6 Sep** | 98 | End | 0.0 | 1.00 | 100 | 64 | 13.4 | 0.0 | 0.0 | 19.1 | **0.44** |
| **13 Sep** | End | End | 10.9 | 1.00 | 100 | 12 | | | | | |

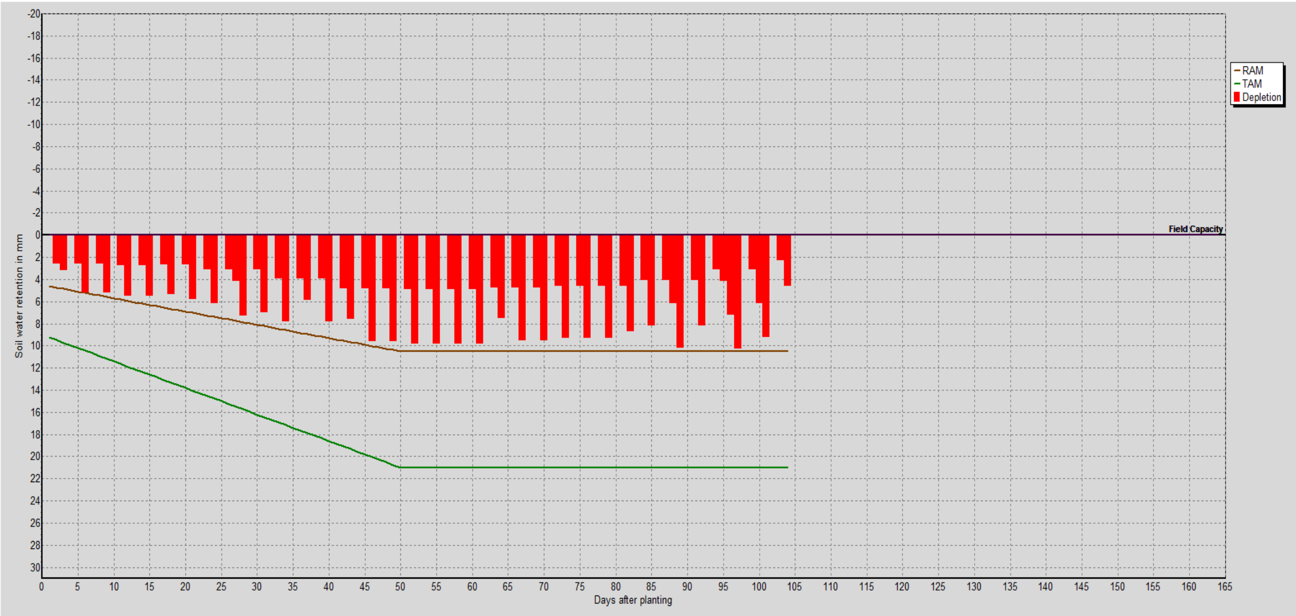


***Figure 19***. *Irrigation scheduling graph per dry year for cucumber.*

***Table 28.*** *Irrigation scheduling per dry year for onion.*

| Date | Day | Stage | Rain | Ks | Eta | Depl. | Net Irr. | Deficit | Loss | Gr. Irr. | FWS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | [mm] | [fract.] | [%] | [%] | [mm] | [mm] | [mm] | [mm] | [l/s/ha] |
| **1 Mar** | 1 | Init | 0.0 | 0.71 | 71 | 59 | 5.4 | 0.0 | 0.0 | 7.8 | **0.90** |
| **22 Mar** | 22 | Dev | 0.0 | 1.00 | 100 | 35 | 4.9 | 0.0 | 0.0 | 7.0 | **0.27** |
| **25 Mar** | 25 | Dev | 0.0 | 1.00 | 100 | 36 | 5.3 | 0.0 | 0.0 | 7.6 | **0.29** |
| **15 Apr** | 46 | Mid | 0.0 | 1.00 | 100 | 44 | 8.0 | 0.0 | 0.0 | 11.4 | **0.44** |
| **21 Apr** | 52 | Mid | 0.0 | 1.00 | 100 | 46 | 8.3 | 0.0 | 0.0 | 11.9 | **0.46** |
| **26 Apr** | 57 | Mid | 0.0 | 1.00 | 100 | 34 | 6.1 | 0.0 | 0.0 | 8.7 | **0.50** |
| **10 May** | 71 | Mid | 0.0 | 1.00 | 100 | 38 | 6.8 | 0.0 | 0.0 | 9.7 | **0.56** |
| **12 May** | 73 | Mid | 0.0 | 1.00 | 100 | 42 | 7.5 | 0.0 | 0.0 | 10.8 | **0.62** |
| **22 May** | 83 | Mid | 0.0 | 1.00 | 100 | 45 | 8.1 | 0.0 | 0.0 | 11.6 | **0.67** |
| **15 Jun** | 107 | Mid | 0.0 | 1.00 | 100 | 51 | 9.2 | 0.0 | 0.0 | 13.1 | **0.76** |
| **29 Jun** | 121 | End | 0.0 | 1.00 | 100 | 51 | 9.1 | 0.0 | 0.0 | 13.0 | **0.75** |
| **1 Jul** | 123 | End | 0.0 | 1.00 | 100 | 50 | 9.0 | 0.0 | 0.0 | 12.9 | **0.75** |
| **19 Jul** | 141 | End | 0.0 | 1.00 | 100 | 48 | 8.6 | 0.0 | 0.0 | 12.3 | **0.71** |
| **28 Jul** | End | End | 0.0 | 1.00 | 0 | 0 | | | | | |

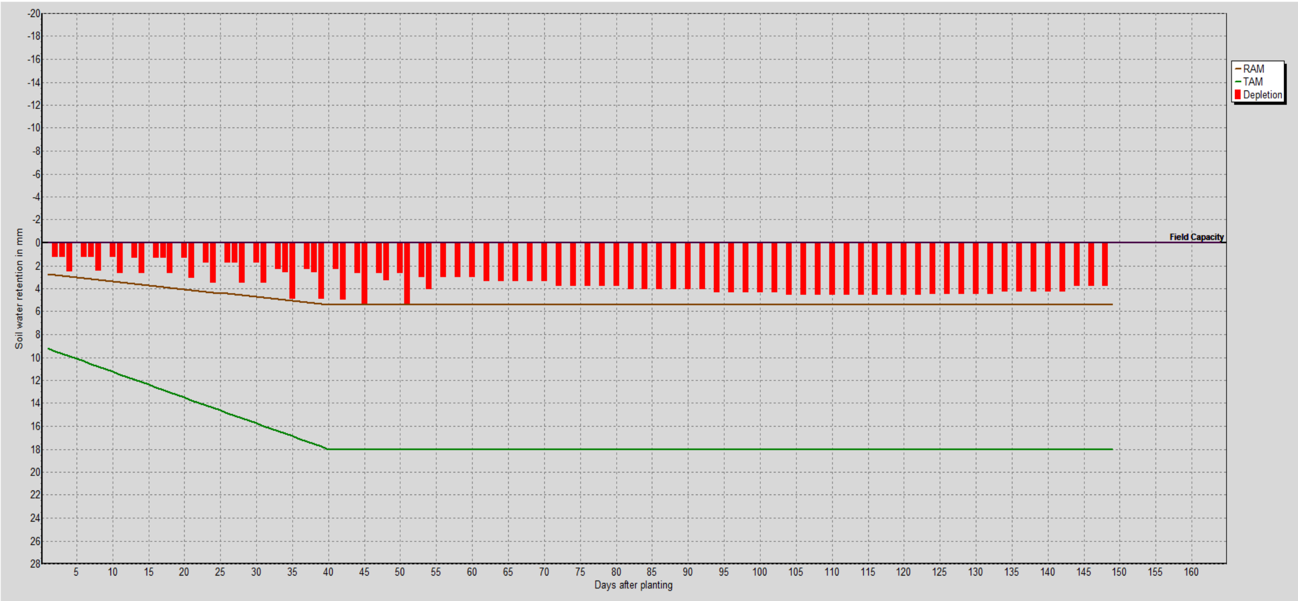


***Figure 20.*** *Irrigation scheduling graph per dry year for onion.*

***Table 29.*** *Irrigation scheduling per dry year for lettuce.*

| Date | Day | Stage | Rain [mm] | Ks [fract.] | Eta [%] | Depl. [%] | Net Irr. [mm] | Deficit [mm] | Loss [mm] | Gr. Irr. [mm] | FWS [l/s/ha] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1 Jun** | 1 | Init | 0.0 | 0.71 | 71 | 73 | 6.6 | 0.0 | 0.0 | 9.5 | **1.09** |
| **2 Jun** | 2 | Init | 0.0 | 1.00 | 100 | 32 | 2.9 | 0.0 | 0.0 | 4.2 | **0.49** |
| **29 Jun** | 29 | Dev | 0.0 | 1.00 | 100 | 56 | 7.0 | 0.0 | 0.0 | 9.9 | **0.58** |
| **10 Jul** | 40 | Dev | 0.0 | 1.00 | 100 | 30 | 4.2 | 0.0 | 0.0 | 5.9 | **0.69** |
| **31 Jul** | 61 | Mid | 0.0 | 1.00 | 100 | 33 | 4.9 | 0.0 | 0.0 | 7.0 | **0.81** |
| **1 Aug** | 62 | Mid | 0.0 | 1.00 | 100 | 31 | 4.7 | 0.0 | 0.0 | 6.7 | **0.78** |
| **12 Aug** | 73 | End | 0.0 | 1.00 | 100 | 59 | 8.9 | 0.0 | 0.0 | 12.7 | **0.73** |
| **14 Aug** | End | End | 0.0 | 1.00 | 100 | 30 | | | | | |

*__Table 30__. Irrigation scheduling per dry year for watermelon.*

| Date | Day | Stage | Rain<br>[mm] | Ks<br>[fract.] | Eta<br>[%] | Depl.<br>[%] | Net Irr.<br>[mm] | Deficit<br>[mm] | Loss<br>[mm] | Gr. Irr.<br>[mm] | FWS<br>[l/s/ha] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1 May** | 1 | Init | 0.0 | 0.83 | 83 | 62 | 5.7 | 0.0 | 0.0 | 8.1 | **0.94** |
| **10 May** | 10 | Init | 0.0 | 1.00 | 100 | 49 | 5.6 | 0.0 | 0.0 | 8.0 | **0.18** |
| **28 May** | 28 | Dev | 0.0 | 1.00 | 100 | 40 | 6.3 | 0.0 | 0.0 | 9.1 | **0.26** |
| **12 Jun** | 43 | Dev | 0.0 | 1.00 | 100 | 43 | 8.3 | 0.0 | 0.0 | 11.8 | **0.68** |
| **14 Jun** | 45 | Dev | 0.0 | 1.00 | 100 | 41 | 8.1 | 0.0 | 0.0 | 11.6 | **0.67** |
| **30 Jun** | 61 | Mid | 0.0 | 1.00 | 100 | 44 | 9.2 | 0.0 | 0.0 | 13.1 | **0.76** |
| **2 Jul** | 63 | Mid | 0.0 | 1.00 | 100 | 46 | 9.7 | 0.0 | 0.0 | 13.9 | **0.80** |
| **20 Jul** | 81 | End | 0.0 | 1.00 | 100 | 49 | 10.2 | 0.0 | 0.0 | 14.6 | **0.84** |
| **30 Jul** | 91 | End | 0.0 | 1.00 | 100 | 44 | 9.3 | 0.0 | 0.0 | 13.2 | **0.77** |
| **1 Aug** | 93 | End | 0.0 | 1.00 | 100 | 41 | 8.7 | 0.0 | 0.0 | 12.4 | **0.72** |
| **16 Aug** | 108 | End | 0.0 | 1.00 | 100 | 52 | 10.8 | 0.0 | 0.0 | 15.5 | **0.60** |
| **18 Aug** | End | End | 0.0 | 1.00 | 100 | 17 | | | | | |

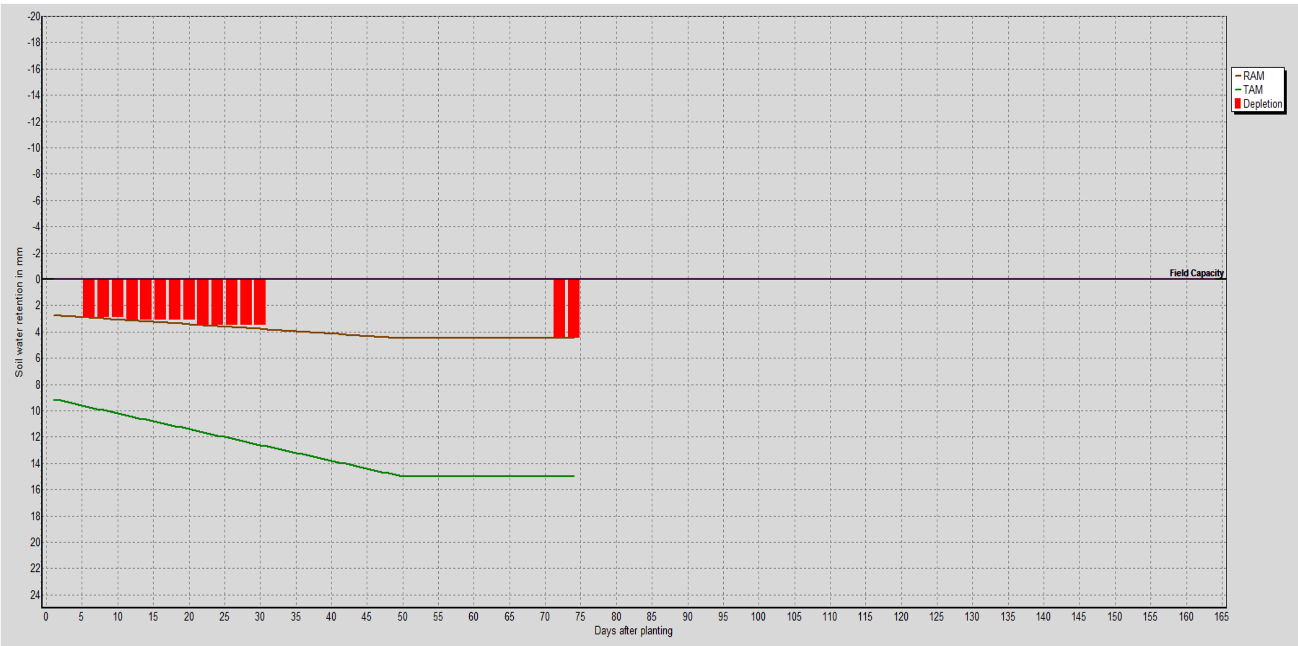


***Figure 21.*** *Irrigation scheduling graph per dry year for lettuce.*

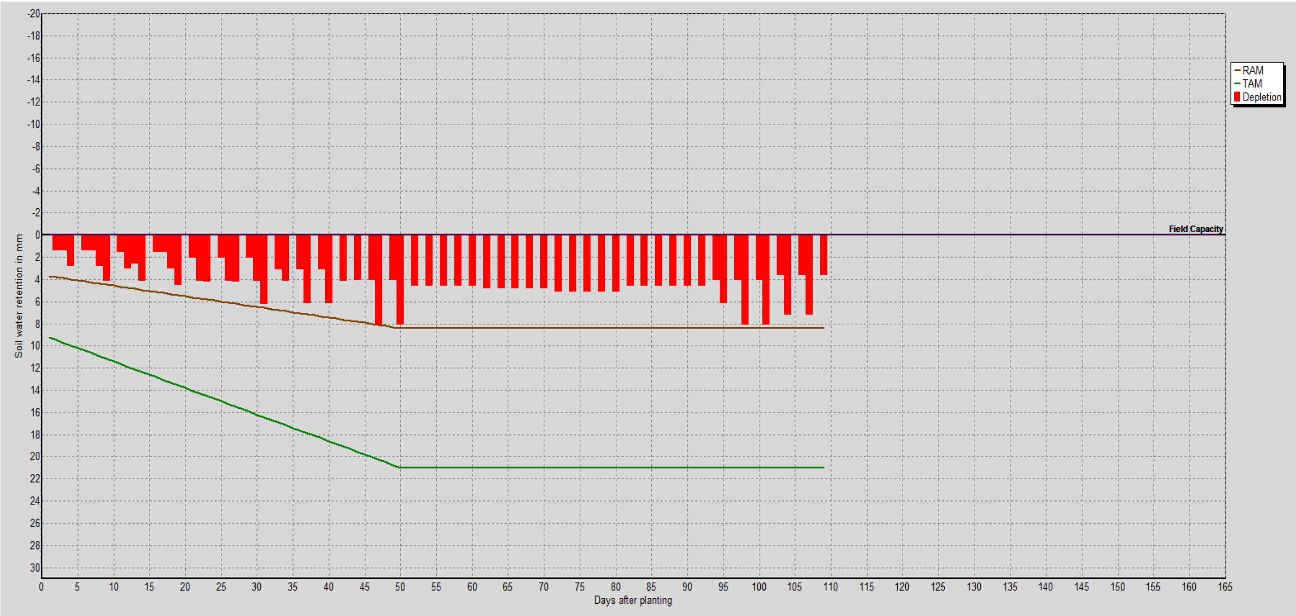


***Figure 22.*** *Irrigation scheduling graph per dry year for watermelon.*

Figures 23.-30. represent irrigation scheduling graphs per average year for eight crops in this diploma thesis, where green line (TAM) is the total available moisture or the total amount of water available to the crop. Brown line (RAM) is the readily available water or the portion of (TAM) that the plant can get from the root zone without facing water stress. Tables 31.-38. illustrate the field crop irrigation schedules (only the biggest month values) for eight crops per average year in this diploma thesis.

***Table 31.*** *Irrigation scheduling per average year for potato.*

| Date | Day | Stage | Rain [mm] | Ks [fract.] | Eta [%] | Depl. [%] | Net Irr. [mm] | Deficit [mm] | Loss [mm] | Gr. Irr. [mm] | FWS [l/s/ha] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1 Apr** | 1 | Init | 0.0 | 0.77 | 77 | 60 | 5.5 | 0.0 | 0.0 | 7.8 | **0.90** |
| **30 Apr** | 30 | Init | 0.0 | 1.00 | 100 | 44 | 5.8 | 0.0 | 0.0 | 8.3 | **0.19** |
| **20 May** | 50 | Dev | 0.0 | 1.00 | 100 | 50 | 8.0 | 0.0 | 0.0 | 11.4 | **0.44** |
| **30 May** | 60 | Dev | 0.0 | 1.00 | 100 | 40 | 6.9 | 0.0 | 0.0 | 9.9 | **0.57** |
| **5 Jun** | 66 | Mid | 0.0 | 1.00 | 100 | 47 | 8.4 | 0.0 | 0.0 | 12.0 | **0.70** |
| **29 Jun** | 90 | Mid | 0.0 | 1.00 | 100 | 53 | 9.5 | 0.0 | 0.0 | 13.5 | **0.78** |
| **1 Jul** | 92 | Mid | 0.0 | 1.00 | 100 | 54 | 9.8 | 0.0 | 0.0 | 13.9 | **0.81** |
| **11 Jul** | 102 | Mid | 0.0 | 1.00 | 100 | 57 | 10.3 | 0.0 | 0.0 | 14.7 | **0.85** |
| **2 Aug** | 124 | End | 0.0 | 1.00 | 100 | 46 | 8.3 | 0.0 | 0.0 | 11.8 | **0.68** |
| **20 Aug** | 142 | End | 0.0 | 1.00 | 100 | 38 | 6.8 | 0.0 | 0.0 | 9.7 | **0.56** |
| **23 Aug** | End | End | 7.2 | 1.00 | 100 | 18 | | | | | |

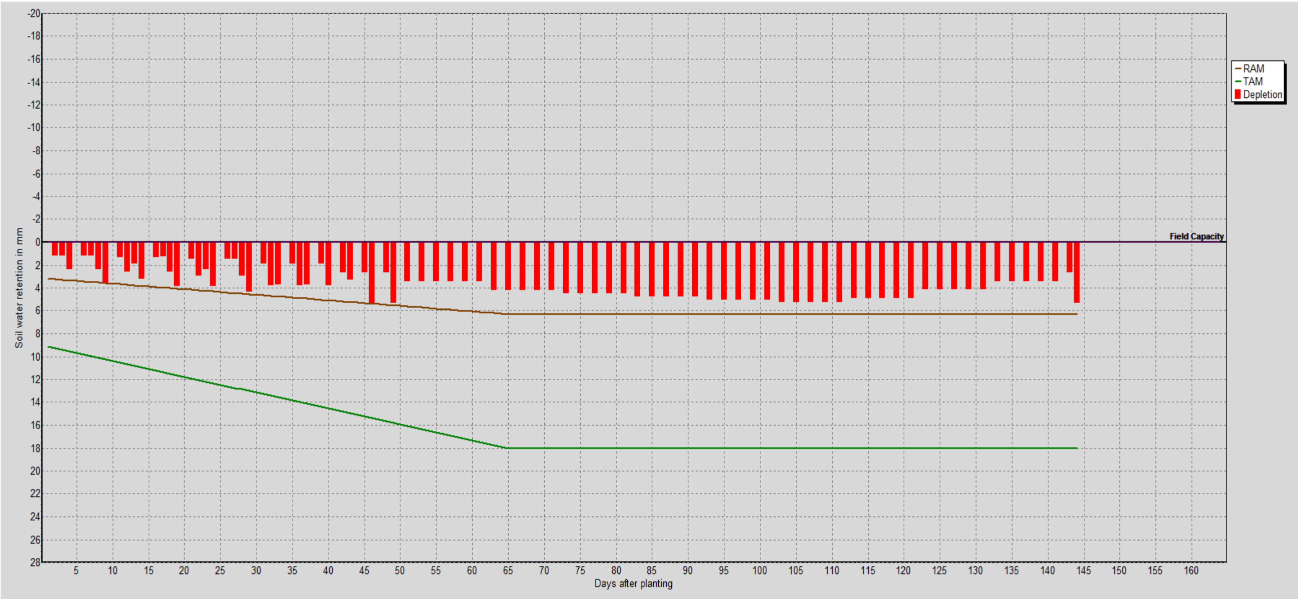


***Figure 23.*** *Irrigation scheduling graph per average year for potato.*

***Table 32.*** *Irrigation scheduling per average year for cabbage.*

| Date | Day | Stage | Rain [mm] | Ks [fract.] | Eta [%] | Depl. [%] | Net Irr. [mm] | Deficit [mm] | Loss [mm] | Gr. Irr. [mm] | FWS [l/s/ha] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1 Apr** | 1 | Init | 0.0 | 0.91 | 91 | 66 | 6.0 | 0.0 | 0.0 | 8.6 | **1.00** |
| **25 Apr** | 25 | Init | 0.0 | 1.00 | 100 | 51 | 6.1 | 0.0 | 0.0 | 8.7 | **0.33** |
| **22 May** | 52 | Dev | 0.0 | 1.00 | 100 | 57 | 8.7 | 0.0 | 0.0 | 12.5 | **0.48** |
| **25 May** | 55 | Dev | 0.0 | 1.00 | 100 | 59 | 9.2 | 0.0 | 0.0 | 13.1 | **0.51** |
| **22 Jun** | 83 | Dev | 0.0 | 1.00 | 100 | 68 | 12.9 | 0.0 | 0.0 | 18.4 | **0.71** |
| **24 Jun** | 85 | Dev | 0.0 | 1.00 | 100 | 46 | 8.9 | 0.0 | 0.0 | 12.7 | **0.74** |
| **20 Jul** | 111 | Mid | 0.0 | 1.00 | 100 | 51 | 10.7 | 0.0 | 0.0 | 15.3 | **0.89** |
| **22 Jul** | 113 | Mid | 0.0 | 1.00 | 100 | 49 | 10.3 | 0.0 | 0.0 | 14.8 | **0.85** |
| **1 Aug** | 123 | Mid | 0.0 | 1.00 | 100 | 48 | 10.2 | 0.0 | 0.0 | 14.5 | **0.84** |
| **4 Aug** | 126 | Mid | 0.0 | 1.00 | 100 | 62 | 13.0 | 0.0 | 0.0 | 18.6 | **0.72** |
| **1 Sep** | 154 | End | 0.0 | 1.00 | 100 | 57 | 12.1 | 0.0 | 0.0 | 17.2 | **0.66** |
| **12 Sep** | End | End | 0.0 | 1.00 | 0 | 30 | | | | | |

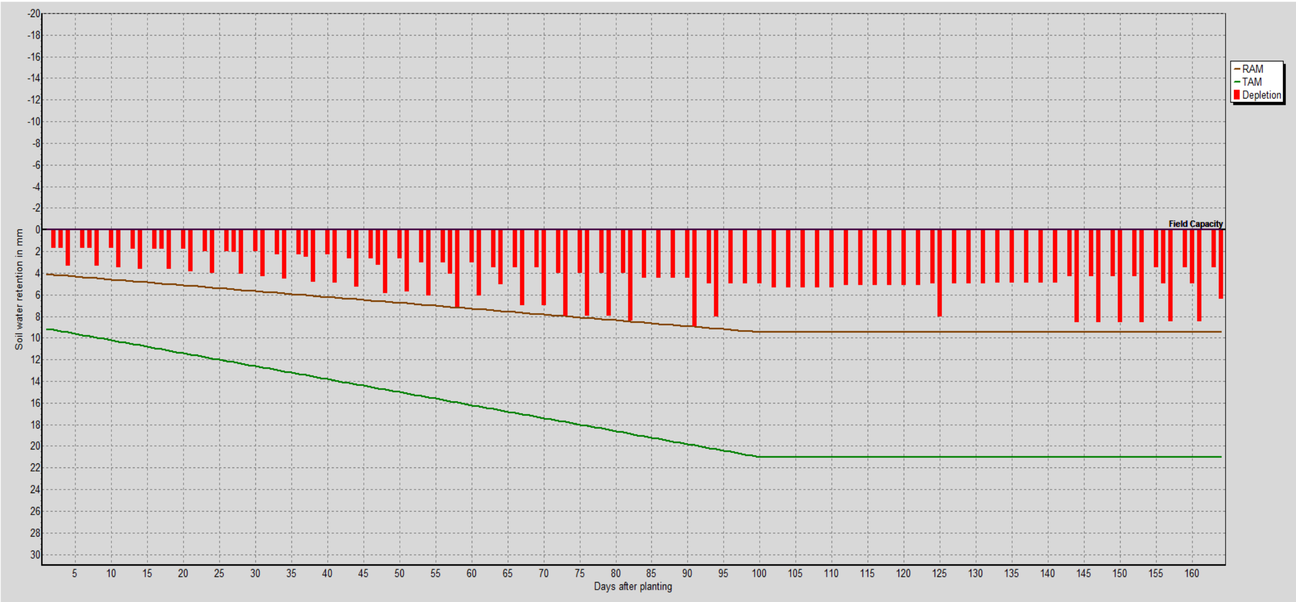


***Figure 24.*** *Irrigation scheduling graph per average year for cabbage.*

***Table 33.*** *Irrigation scheduling per average year for tomato.*

| Date | Day | Stage | Rain [mm] | Ks [fract.] | Eta [%] | Depl. [%] | Net Irr. [mm] | Deficit [mm] | Loss [mm] | Gr. Irr. [mm] | FWS [l/s/ha] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1 Apr** | 1 | Init | 0.0 | 0.83 | 83 | 63 | 5.7 | 0.0 | 0.0 | 8.2 | **0.95** |
| **15 Apr** | 15 | Init | 0.0 | 1.00 | 100 | 40 | 4.7 | 0.0 | 0.0 | 6.7 | **0.26** |
| **30 Apr** | 30 | Init | 0.0 | 1.00 | 100 | 50 | 7.0 | 0.0 | 0.0 | 10.0 | **0.23** |
| **4 May** | 34 | Dev | 0.0 | 1.00 | 100 | 46 | 6.8 | 0.0 | 0.0 | 9.8 | **0.28** |
| **20 May** | 50 | Dev | 0.0 | 1.00 | 100 | 50 | 8.8 | 0.0 | 0.0 | 12.6 | **0.49** |
| **1 Jun** | 62 | Dev | 0.0 | 1.00 | 100 | 42 | 8.2 | 0.0 | 0.0 | 11.7 | **0.68** |
| **30 Jun** | 91 | Mid | 0.0 | 1.00 | 100 | 50 | 10.5 | 0.0 | 0.0 | 15.1 | **0.87** |
| **2 Jul** | 93 | Mid | 0.0 | 1.00 | 100 | 53 | 11.2 | 0.0 | 0.0 | 16.0 | **0.92** |
| **12 Jul** | 103 | Mid | 0.0 | 1.00 | 100 | 56 | 11.7 | 0.0 | 0.0 | 16.8 | **0.97** |
| **1 Aug** | 123 | End | 0.0 | 1.00 | 100 | 50 | 10.5 | 0.0 | 0.0 | 15.0 | **0.87** |
| **23 Aug** | End | End | 21.4 | 1.00 | 100 | 26 | | | | | |

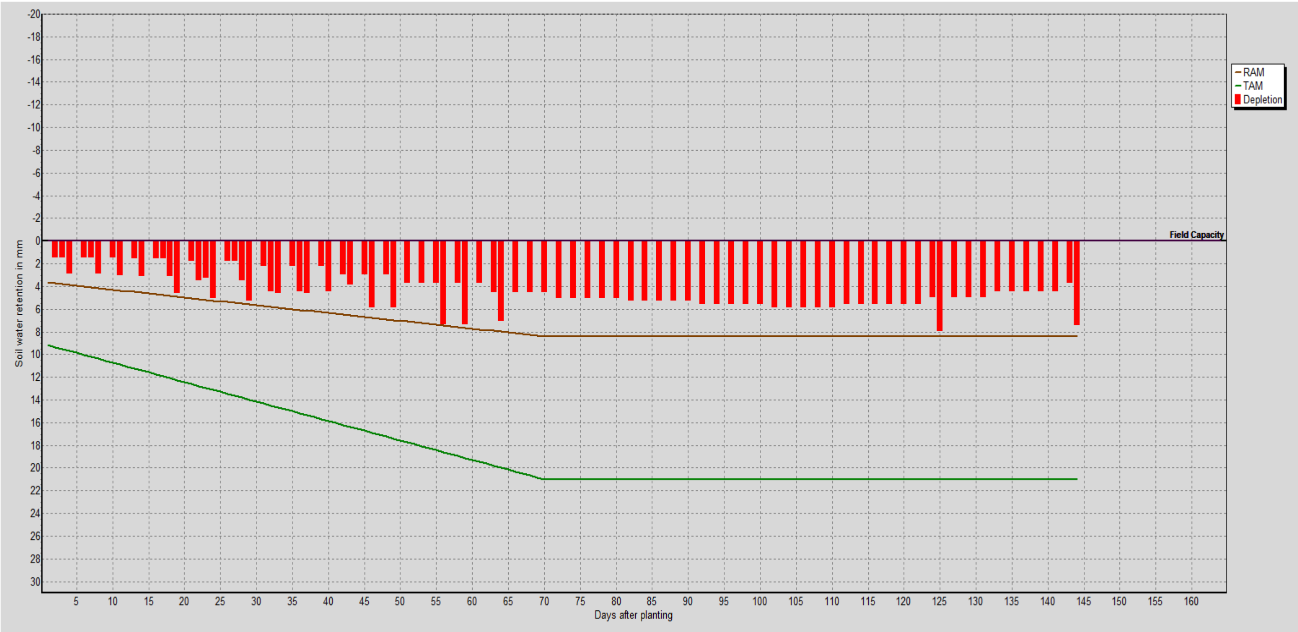


***Figure 25.*** *Irrigation scheduling graph per average year for tomato.*

***Table 34.*** *Irrigation scheduling per average year for pepper.*

| Date | Day | Stage | Rain [mm] | Ks [fract.] | Eta [%] | Depl. [%] | Net Irr. [mm] | Deficit [mm] | Loss [mm] | Gr. Irr. [mm] | FWS [l/s/ha] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1 May** | 1 | Init | 0.0 | 0.71 | 71 | 65 | 6.0 | 0.0 | 0.0 | 8.5 | **0.99** |
| **12 May** | 12 | Init | 0.0 | 1.00 | 100 | 40 | 4.4 | 0.0 | 0.0 | 6.3 | **0.37** |
| **30 May** | 30 | Init | 0.0 | 1.00 | 100 | 32 | 4.6 | 0.0 | 0.0 | 6.6 | **0.38** |
| **10 Jun** | 41 | Dev | 0.0 | 1.00 | 100 | 34 | 5.6 | 0.0 | 0.0 | 8.0 | **0.46** |
| **12 Jun** | 43 | Dev | 0.0 | 1.00 | 100 | 42 | 7.1 | 0.0 | 0.0 | 10.1 | **0.59** |
| **30 Jun** | 61 | Dev | 0.0 | 1.00 | 100 | 43 | 8.6 | 0.0 | 0.0 | 12.3 | **0.71** |
| **10 Jul** | 71 | Mid | 0.0 | 1.00 | 100 | 48 | 10.1 | 0.0 | 0.0 | 14.5 | **0.84** |
| **12 Jul** | 73 | Mid | 0.0 | 1.00 | 100 | 51 | 10.7 | 0.0 | 0.0 | 15.3 | **0.89** |
| **30 Jul** | 91 | Mid | 0.0 | 1.00 | 100 | 49 | 10.3 | 0.0 | 0.0 | 14.8 | **0.85** |
| **1 Aug** | 93 | Mid | 0.0 | 1.00 | 100 | 48 | 10.2 | 0.0 | 0.0 | 14.5 | **0.84** |
| **9 Aug** | 101 | Mid | 0.0 | 1.00 | 100 | 48 | 10.0 | 0.0 | 0.0 | 14.3 | **0.83** |
| **19 Aug** | 111 | End | 0.0 | 1.00 | 100 | 45 | 9.5 | 0.0 | 0.0 | 13.6 | **0.79** |
| **1 Sep** | 124 | End | 0.0 | 1.00 | 100 | 34 | 7.1 | 0.0 | 0.0 | 10.1 | **0.59** |
| **2 Sep** | End | End | 15.8 | 1.00 | 0 | 0 | | | | | |

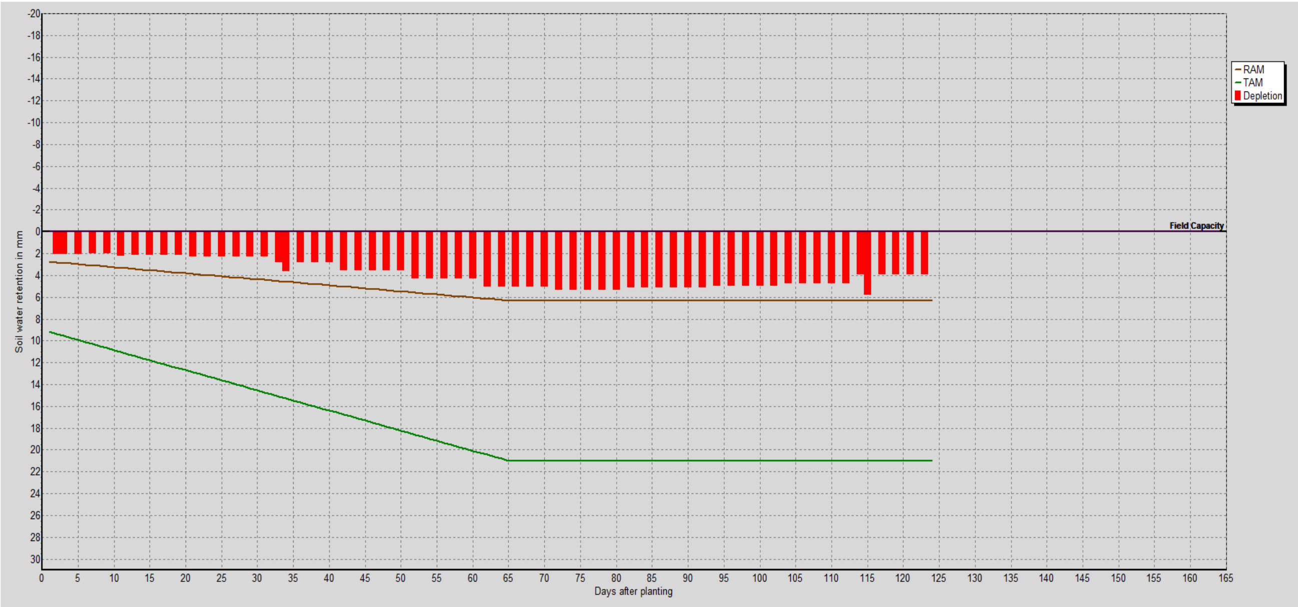


***Figure 26.*** *Irrigation scheduling graph per average year for pepper.*

***Table 35****. Irrigation scheduling per average year for cucumber.*

| Date | Day | Stage | Rain | Ks | Eta | Depl. | Net Irr. | Deficit | Loss | Gr. Irr. | FWS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | [mm] | [fract.] | [%] | [%] | [mm] | [mm] | [mm] | [mm] | [l/s/ha] |
| **1 Jun** | 1 | Init | 0.0 | 1.00 | 100 | 77 | 7.1 | 0.0 | 0.0 | 10.1 | **1.17** |
| **22 Jun** | 22 | Dev | 0.0 | 1.00 | 100 | 63 | 9.0 | 0.0 | 0.0 | 12.8 | **0.49** |
| **25 Jun** | 25 | Dev | 0.0 | 1.00 | 100 | 62 | 9.3 | 0.0 | 0.0 | 13.2 | **0.51** |
| **11 Jul** | 41 | Dev | 0.0 | 1.00 | 100 | 67 | 12.6 | 0.0 | 0.0 | 18.1 | **0.70** |
| **20 Jul** | 50 | Dev | 0.0 | 1.00 | 100 | 69 | 14.4 | 0.0 | 0.0 | 20.6 | **0.79** |
| **29 Jul** | 59 | Mid | 0.0 | 1.00 | 100 | 70 | 14.8 | 0.0 | 0.0 | 21.1 | **0.81** |
| **1 Aug** | 62 | Mid | 0.0 | 1.00 | 100 | 70 | 14.6 | 0.0 | 0.0 | 20.9 | **0.80** |
| **10 Aug** | 71 | Mid | 0.0 | 1.00 | 100 | 68 | 14.3 | 0.0 | 0.0 | 20.4 | **0.79** |
| **1 Sep** | 93 | End | 0.0 | 1.00 | 100 | 53 | 11.2 | 0.0 | 0.0 | 16.0 | **0.62** |
| **10 Sep** | 102 | End | 0.0 | 1.00 | 100 | 59 | 12.3 | 0.0 | 0.0 | 17.6 | **0.51** |
| **13 Sep** | End | End | 0.0 | 1.00 | 0 | 12 | | | | | |

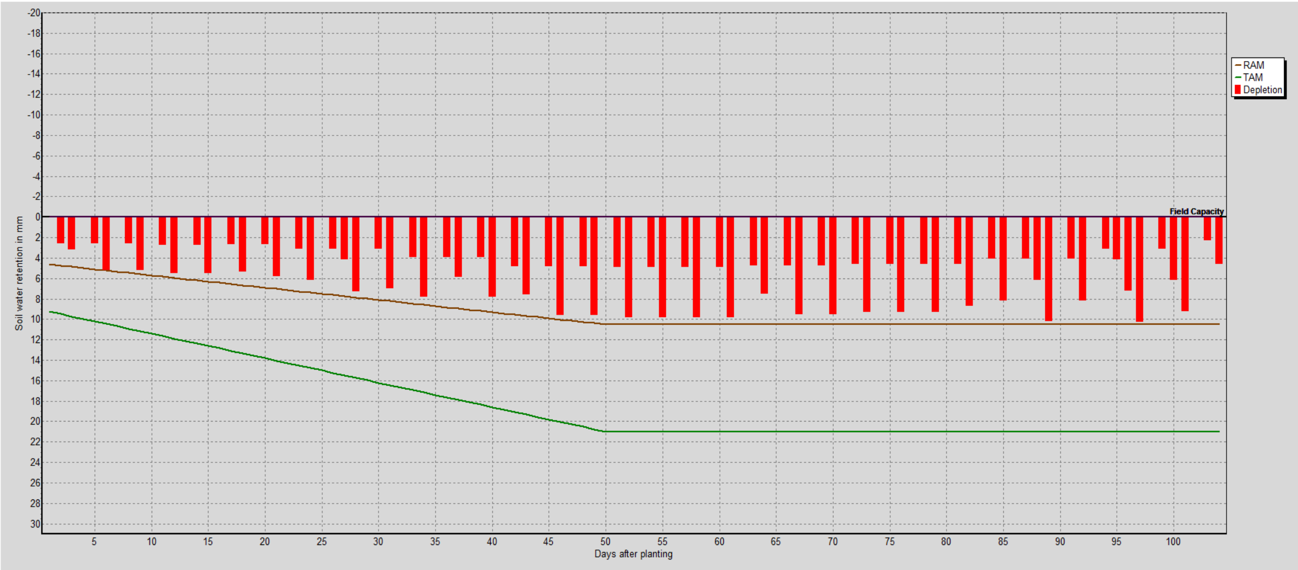


***Figure 27.*** *Irrigation scheduling graph per average year for cucumber.*

***Table 36.*** *Irrigation scheduling per average year for onion.*

| Date | Day | Stage | Rain | Ks | Eta | Depl. | Net Irr. | Deficit | Loss | Gr. Irr. | FWS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | [mm] | [fract.] | [%] | [%] | [mm] | [mm] | [mm] | [mm] | [l/s/ha] |
| **1 Mar** | 1 | Init | 0.0 | 0.71 | 71 | 59 | 5.4 | 0.0 | 0.0 | 7.8 | **0.90** |
| **22 Mar** | 22 | Dev | 0.0 | 1.00 | 100 | 35 | 4.9 | 0.0 | 0.0 | 7.0 | **0.27** |
| **25 Mar** | 25 | Dev | 0.0 | 1.00 | 100 | 36 | 5.3 | 0.0 | 0.0 | 7.6 | **0.29** |
| **15 Apr** | 46 | Mid | 0.0 | 1.00 | 100 | 44 | 8.0 | 0.0 | 0.0 | 11.4 | **0.44** |
| **21 Apr** | 52 | Mid | 0.0 | 1.00 | 100 | 46 | 8.3 | 0.0 | 0.0 | 11.9 | **0.46** |
| **26 Apr** | 57 | Mid | 0.0 | 1.00 | 100 | 34 | 6.1 | 0.0 | 0.0 | 8.7 | **0.50** |
| **10 May** | 71 | Mid | 0.0 | 1.00 | 100 | 38 | 6.8 | 0.0 | 0.0 | 9.7 | **0.56** |
| **12 May** | 73 | Mid | 0.0 | 1.00 | 100 | 42 | 7.5 | 0.0 | 0.0 | 10.8 | **0.62** |
| **30 May** | 91 | Mid | 0.0 | 1.00 | 100 | 45 | 8.1 | 0.0 | 0.0 | 11.6 | **0.67** |
| **21 Jun** | 113 | End | 0.0 | 1.00 | 100 | 51 | 9.1 | 0.0 | 0.0 | 13.0 | **0.76** |
| **29 Jun** | 121 | End | 0.0 | 1.00 | 100 | 51 | 9.1 | 0.0 | 0.0 | 13.0 | **0.75** |
| **1 Jul** | 123 | End | 0.0 | 1.00 | 100 | 50 | 9.0 | 0.0 | 0.0 | 12.9 | **0.75** |
| **21 Jul** | 143 | End | 0.0 | 1.00 | 100 | 45 | 8.1 | 0.0 | 0.0 | 11.6 | **0.67** |
| **28 Jul** | End | End | 0.0 | 1.00 | 0 | 0 | | | | | |

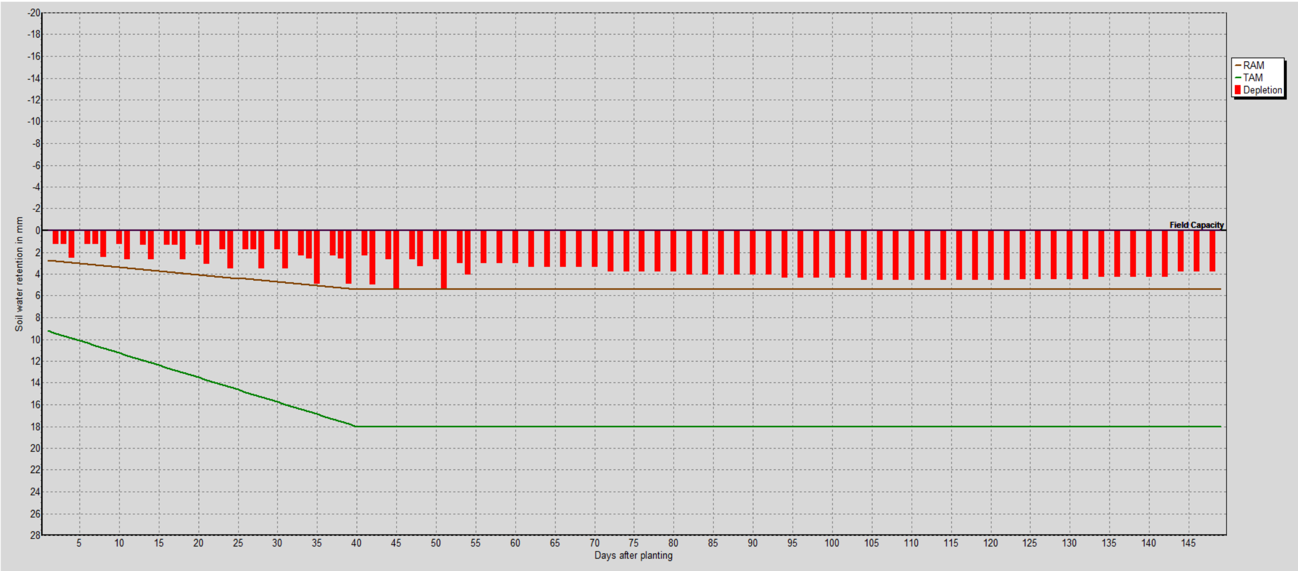


***Figure 28.*** *Irrigation scheduling graph per average year for onion.*

***Table 37.*** *Irrigation scheduling per average year for lettuce.*

| Date | Day | Stage | Rain [mm] | Ks [fract.] | Eta [%] | Depl. [%] | Net Irr. [mm] | Deficit [mm] | Loss [mm] | Gr. Irr. [mm] | FWS [l/s/ha] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1 Jun** | 1 | Init | 0.0 | 0.71 | 71 | 73 | 6.6 | 0.0 | 0.0 | 9.5 | **1.09** |
| **25 Jun** | 25 | Dev | 0.0 | 1.00 | 100 | 58 | 7.0 | 0.0 | 0.0 | 9.9 | **0.58** |
| **30 Jul** | 60 | Mid | 0.0 | 1.00 | 100 | 33 | 4.9 | 0.0 | 0.0 | 7.0 | **0.81** |
| **10 Aug** | 71 | End | 0.0 | 1.00 | 100 | 31 | 4.7 | 0.0 | 0.0 | 6.7 | **0.78** |
| **14 Aug** | End | End | 0.0 | 1.00 | 100 | 30 | | | | | |

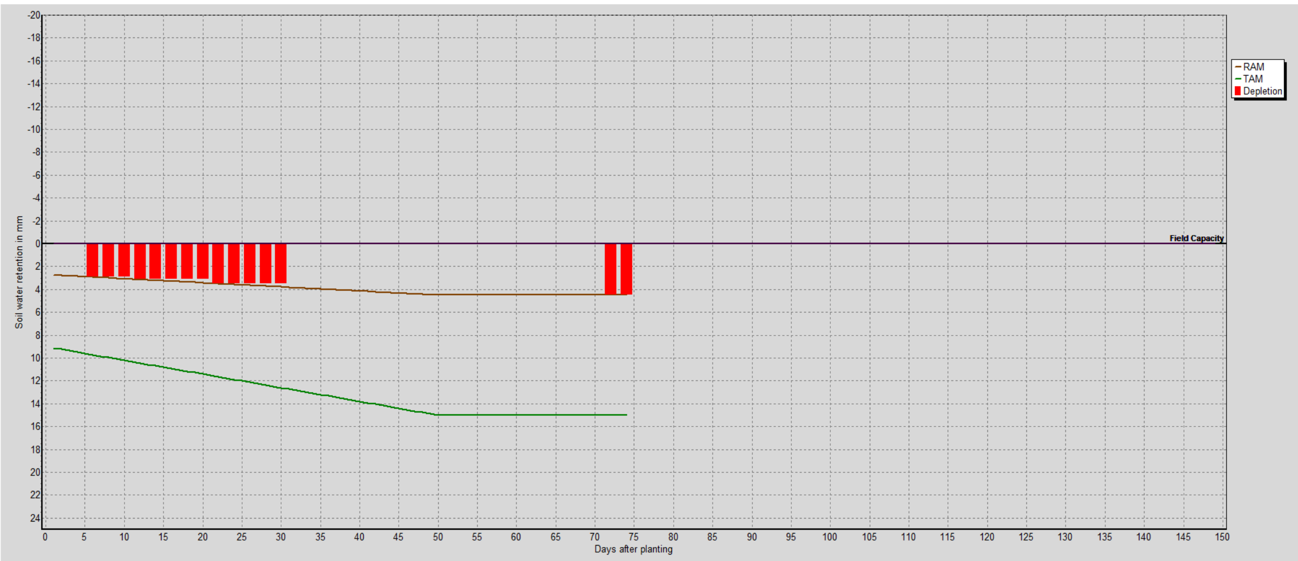


***Figure 29****. Irrigation scheduling graph per average year for lettuce.*

***Table 38.*** *Irrigation scheduling per average year for watermelon.*

| Date | Day | Stage | Rain [mm] | Ks [fract.] | Eta [%] | Depl. [%] | Net Irr. [mm] | Deficit [mm] | Loss [mm] | Gr. Irr. [mm] | FWS [l/s/ha] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1 May** | 1 | Init | 0.0 | 0.83 | 83 | 62 | 5.7 | 0.0 | 0.0 | 8.1 | **0.94** |
| **28 May** | 28 | Dev | 0.0 | 1.00 | 100 | 40 | 6.3 | 0.0 | 0.0 | 9.1 | **0.26** |
| **12 Jun** | 43 | Dev | 0.0 | 1.00 | 100 | 43 | 8.3 | 0.0 | 0.0 | 11.8 | **0.68** |
| **30 Jun** | 61 | Mid | 0.0 | 1.00 | 100 | 44 | 9.2 | 0.0 | 0.0 | 13.1 | **0.76** |
| **2 Jul** | 63 | Mid | 0.0 | 1.00 | 100 | 46 | 9.7 | 0.0 | 0.0 | 13.9 | **0.80** |
| **18 Jul** | 79 | Mid | 0.0 | 1.00 | 100 | 49 | 10.2 | 0.0 | 0.0 | 14.6 | **0.84** |
| **28 Jul** | 89 | End | 0.0 | 1.00 | 100 | 44 | 9.3 | 0.0 | 0.0 | 13.2 | **0.77** |
| **1 Aug** | 93 | End | 0.0 | 1.00 | 100 | 41 | 8.7 | 0.0 | 0.0 | 12.4 | **0.72** |
| **10 Aug** | 102 | End | 0.0 | 1.00 | 100 | 58 | 12.2 | 0.0 | 0.0 | 17.4 | **0.67** |
| **16 Aug** | 108 | End | 0.0 | 1.00 | 100 | 52 | 10.8 | 0.0 | 0.0 | 15.5 | **0.60** |
| **18 Aug** | End | End | 0.0 | 1.00 | 100 | 17 | | | | | |

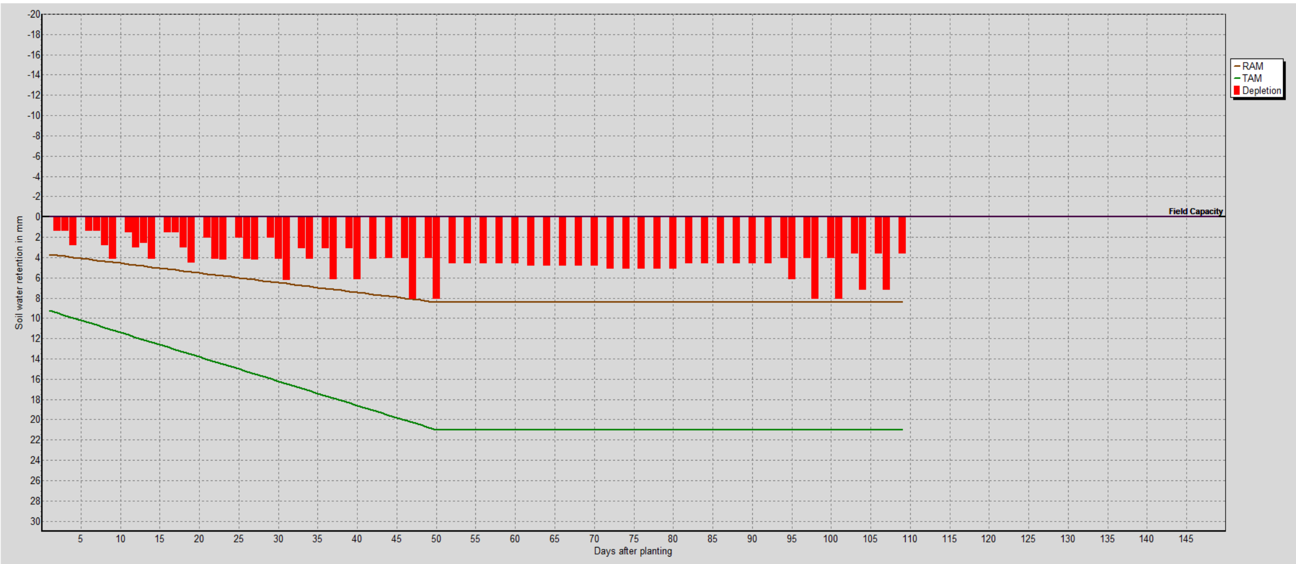


***Figure 30****. Irrigation scheduling graph per average year for watermelon.*

# 7. Suitable irrigation systems

Taking into account the natural and technical conditions in the considered area, it is planned to install a drip irrigation system and micro-sprinkler irrigation system. These systems work on the principle that water from the system of installed plastic pipes exits through special droppers or micro-sprinklers that are placed along the pipe and by dripping or small spraying water moistens the soil next to each plant. Water is brought to each plant and a small part of the surface is moistened so water losses are small or there are none at all. The addition of water can be continuous (lasts from 0 to 24 hours) or occasionally (at certain intervals). This means that it is possible to maintain soil moisture in the active zone of the roots of each plant near the value of the field water capacity.

## 7.1. Drip irrigation system

Drip irrigation system is also commonly referred to as "trickle" or "low flow" irrigation. The basic concept of drip irrigation is to provide near-optimal soil moisture on a continuous basis while conserving water. Plants respond favorably to the soil moisture regime afforded with drip irrigation and larger, healthier plants can be expected in a given growth period.

Drip irrigation is a system that applies water directly to individual plants, as opposed to the sprinkler system, which irrigates all of the surface areas. This is accomplished by relatively small-diameter lateral pipes with "emitters" attached to supply each plant with water. Emitters are the key devices within the system. They are available in many sizes and shapes. Various emitters incorporate quite different hydraulic methods to reduce pressure and create one or two gallon per hour (GPH) flow. Some emitters have multiple outlets and some multiple outlet emitters even allow for differing flow rates from individual laterals. Emitter selection is primarily dependent on factors such as flow characteristics, filtration requirements, cost, and local availability.

Emitters can be generally classified into two categories - point source and aerosol. A point source emitter drips water directly to the soil surface. The soil volume directly under the emitter may be saturated during system operation and immediately thereafter. The aerosol emitter throws water through the air for some distance before water contacts the soil surface.

Drip irrigation requires careful water treatment to prevent emitter blockage problems. Frequent inspection of the system is necessary to ensure it is functioning properly. Improper design and component sizing can result in a system with poor uniformity of application and a much lower than expected application efficiency.

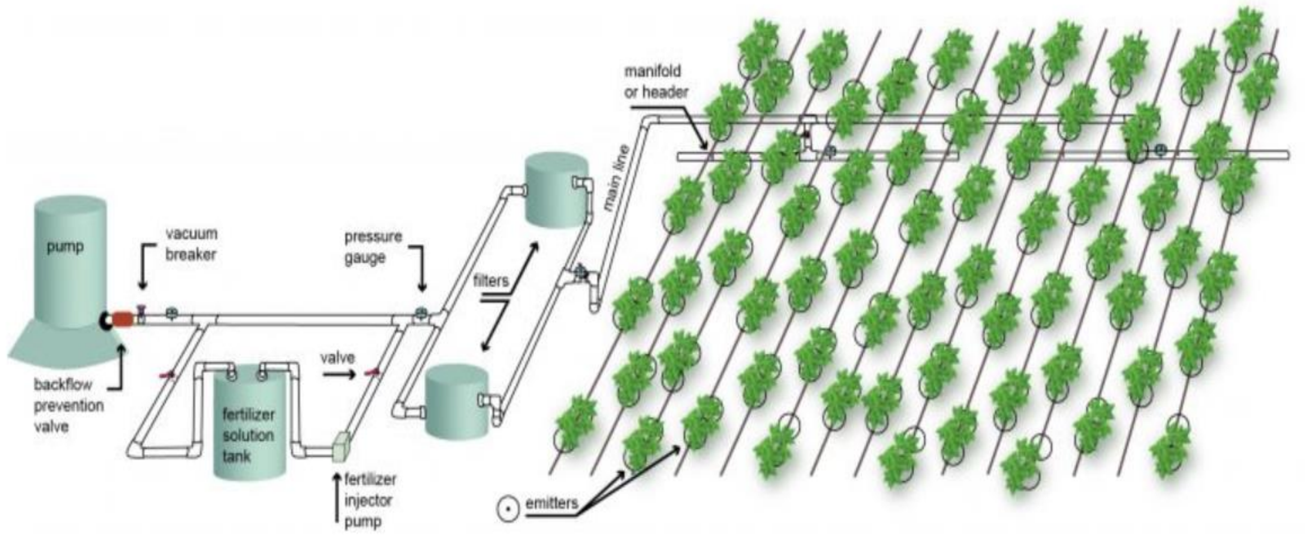


***Figure 31.*** *Typical drip irrigation system [19.].*

The components of the drip irrigation system are classified into the following principal categories:

- Pump and prime mover; the pressure necessary to force water through the components of the system including fertilizer tank, filter unit, mainline, sub-main, laterals and provide at the emitters at the desired pressure is obtained by a pump of suitable capacity or the overhead water tank located at a suitable elevation.

- Water sources such as a river, lake, reservoir/tank, well, open canal water supply or connection to a public commercial or cooperative water supply network can be used. Drip irrigation is a pressurized irrigation technology in which water is delivered from these sources by increasing its internal energy (pressure) by pumping.

- Pipe network such as mainline, sub-domains, and manifolds (feeder pipes) and laterals.

- Emitting devices such as emitters or drippers or the laterals integrated with drippers/emitters and line sources with drippers.

- Control devices such as valves, flow meters, pressure and flow regulators, automation equipment, backflow preventers, vacuum, and air release valves.

- Filtration devices are used for removal of suspended materials in the water, such as media, screen, and disc filters.

- Chemical injectors are used for the application of plant nutrients and water treatment agents along with the irrigation water such as pressurized tank, venture injector, injection pump.

*Table 39. Advantages and disadvantages of drip irrigation [11.].*

| Advantages | Disadvantages |
|---|---|
| Precise placement of water in the plant root zone. | Filtration required to prevent emitter clogging. |
| Reduced weed growth. | Proper management more complex. |
| Minimal evaporative losses. | Adaptation can be more involved than with sprinkler irrigation. |
| High application efficiency. | First indication of maintenance problems (emitters clogged) may show up only after plants are stressed. |
| Low flow rates relative to sprinkler irrigation. | |
| Evaporation and overland flow minimized. | |
| Lower installed unit cost than sprinklers. | |
| Favorable plant response (larger, healthier plant materials over time). | |
| Flexible operating hours, considering possible irrigation during daytime hours, high wind conditions, and with pedestrians present. | |
| Flexibility to add emitters if plants are added. | |
| Relatively easy to introduce water-soluble fertilizers and chemicals into irrigation system. | |

## 7.2. Micro-sprinkler irrigation system

The Micro-sprinkler irrigation system is a newer way of localized irrigation. Water falls to the surface of the soil in the form of a small jet or mist.

The system operates at a lower pressure of 1.0 bar to 2.5 bar, and the irrigation intensity is lower, from 20 to 80 l / h. Only the part of the surface where the main root mass develops is irrigated. This irrigation system provides low precipitation rates, making them suitable for longer watering time with less run off.

It is most often used for crops that are planted at larger intervals (woody fruit crops and vineyards) and for crops that need frequent irrigation in smaller quantities (vegetable crops).

The system consists of pump at the water source, pressure regulator, water meter, various control valves, plastic pipes for supplying and distributing water per plot, and mini sprinklers. Due to higher flow and working pressure mini sprinklers are less clogged compared to droppers.

The main pipeline and lateral pipes are made of flexible plastic, polyethylene pipes to which set up by mini sprinklers. There are different forms of attachments and brackets for mini sprinklers.

Today, mini sprayers are produced in various designs, shapes, and types. They have different flows, ranges, operate under different pressures, and distribute water evenly throughout the range of spray. Mini sprayers excellently irrigate the terrain and crops, but they also serve as regulators of the microclimate because relative humidity can increase under their operation.

Each mini sprayer has its own features that can be found described in the catalogs and offers of equipment manufacturers. Using catalogs and technical documentation is important to choose a mini sprayer for specific crops and conditions.

The advantages of micro-sprinkler irrigation system are:

- The reduced possibility of clogging.
- A larger range of irrigated surfaces and increase the relative humidity.
- The entire device can be mounted very quickly and dismantled at the end of the season.

The disadvantages of micro-sprinkler irrigation system are:

- The sensitivity in windy areas and in areas of high evapotranspiration.
- This system consumes more water than the drip system.

# 8. Proposed technical solution

The proposed technical solution depends on the irrigation areas, on the amount of water for irrigation, and on a suitable irrigation system.

The irrigation area is 32 hectares, and crops for irrigation are potato, cabbage, tomato, pepper, cucumber, onion, lettuce, and watermelon. According to computer program CROPWAT 8.0. calculated total annual gross amounts of irrigation water need are 44. 826, 03 $m^3$ for an average year, and 91. 324, 80 $m^3$ for a dry year.

As suitable irrigation systems it is planned to install a drip irrigation system and micro-sprinkler irrigation system.

Due to no permanent surface flows and insufficient water amount in the ground, an appropriate approach would be building micro- accumulation that would be recharged in the winter period with rainwater and used for irrigation. The rainwater from the micro-accumulation system can be of consistently high quality through the selection of appropriate catchment and storage materials and the application of post-cistern treatment.

## 8.1. Water abstraction

As there are no permanent surface flows in the area of question, water intake from these sources is excluded. On the other side, as the whole wider area is of karst type, and mainly within the coverage area there are soils with intergranular porosity, it can be concluded that the amounts of water in the ground are insufficient for their use for irrigation purposes. The appropriate approach would be building micro- accumulation that would be recharged in the winter period and used for irrigation. The subject area is extremely suitable for this type of intervention because there are numerous valleys that could, with a relatively small amount of earthwork serve to accumulate water.

A survey of the terrain there is identified three potential sites for the construction of a micro-accumulation. Figure 33. shows three potential places for the construction of a micro-accumulation.

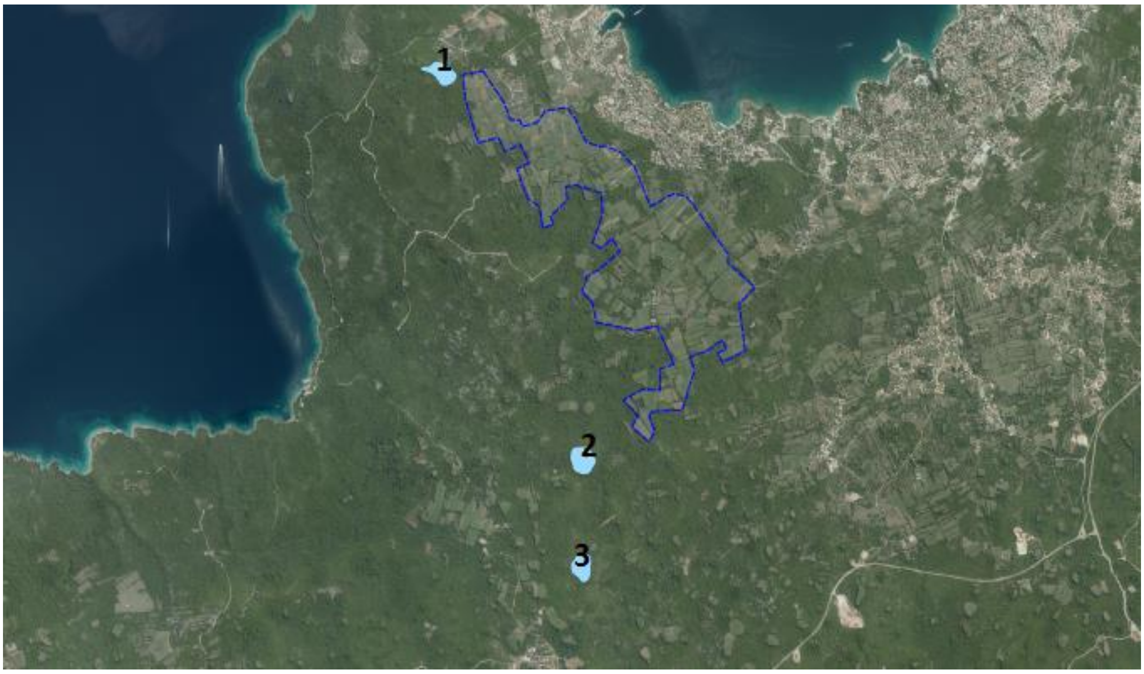


***Figure 32.*** *Positions of micro-accumulations for three different solutions.*

The micro-accumulation area for solution 1 is located northeast of the subject area. The large depth of the valley reduces the earthworks costs, although certain excavations could still be expected in the eastern (shallower) part of the reservoir. In addition, it would be necessary to build a plateau for water intake and a pumping station, since according to the current situation there is no space for that. Compared to other solutions, the bottom of the micro-accumulation would be located at a lower altitude (Figure 34.).

***Figure 33.*** *The bottom of the valley for micro accumulation according to solution 1.*

The micro-accumulation area for solution 2 is located south of the subject area. The current state of the space is shown in figure 34. The valley is a relatively regular concave shape and minimal excavation can be expected.

***Figure 34.*** *Bottom of the valley for micro accumulation according to solution 2.*

The micro-accumulation area for solution 3 is located south of the subject area, near the settlement Poljice. The bottom of the accumulation is high enough that water can be delivered to irrigation surfaces by gravity. In addition to the expected quantities of earthworks, the construction of an embankment in the northern part of the micro-accumulation can be also expected.
For the purpose of this Master thesis, the micro-accumulation area for solution three is chosen as the most appropriate solution. The micro-accumulation for a solution three is at a sufficient altitude that the pressures in the system are satisfied for the gravitational water flow.

## 8.2. Description of irrigation water distribution to irrigation surfaces

The supply of water from the micro-reservoirs to the irrigation surfaces is provided by buried pipes under pressure. For the chosen micro-accumulation variant, the pipelines are run along roads, i.e. public goods, which avoids additional costs and time for resolving property and legal affairs. A 200 mm diameter pipeline runs from the micro-reservoirs themselves, which satisfies the working hydro module of irrigation. In the distribution area, depending on the results of the hydraulic calculation below, pipes with a diameter of 150 mm and 100 mm are run.

The total length of distribution pipelines is 6,229 m, while the length of the supply pipeline is 901 m.

# 9. Hydraulic analysis

In this Master Thesis, the EPANET program was used for the calculation of the hydraulic analysis. The purpose of the hydraulic analysis was to define the pressures in the system which have to be sufficient for localized irrigation by drip irrigation or micro-sprinklers irrigation system. The pressures in such a system have to be ≥ 3.5 bar.

The EPANET is a computer program that performs extended period simulation of hydraulic and water quality behavior within pressurized pipe networks. A network consists of pipes, pipe junctions, pumps, valves and storage tanks or reservoirs. The computer program solves the nonlinear energy equations and linear mass equations for pressures at nodes and flowrates in pipes.

## 9.1. Input data

The EPANET input data includes descriptions of the physical characteristics of pipes and nodes and the connectivity of the pipes in a pipe network system. The pipe parameters include the length, inside diameter and roughness coefficient of the pipe (Table 40.). The parameters of nodes consist of the base demand, elevation, horizontal and vertical location (Table 41.).

***Table 40**. Pipe input parameters.*

| Link ID | Length [m] | Diameter [mm] | Roughness [mm] |
|---|---|---|---|
| Pipe 21 | 376.75 | 100.00 | 0.10 |
| Pipe 14 | 304.71 | 100.00 | 0.10 |
| Pipe 15 | 196.81 | 200.00 | 0.10 |
| Pipe 18 | 1137.34 | 150.00 | 0.10 |
| Pipe 16 | 278.11 | 100.00 | 0.10 |
| Pipe 19 | 341.11 | 100.00 | 0.10 |
| Pipe 20 | 930.35 | 150.00 | 0.10 |
| Pipe 13 | 627.80 | 200.00 | 0.10 |
| Pipe 17 | 467.33 | 100.00 | 0.10 |
| Pipe 12 | 1000.00 | 200.00 | 0.10 |


***Figure 35.*** *Pipes positions.*

***Table 41.*** *Node input parameters.*

| Node ID | Elevation [m] | Base Demand [l/s] |
|---|---|---|
| Junction 11 | 48.19 | 2.41 |
| Junction 10 | 42.83 | 2.91 |
| Junction 3 | 37.80 | 2.21 |
| Junction 4 | 32.57 | 5.01 |
| Junction 5 | 35.86 | 1.45 |
| Junction 8 | 33.36 | 3.18 |
| Junction 7 | 28.64 | 1.01 |
| Junction 2 | 47.43 | 2.76 |
| Junction 9 | 38.80 | 3.67 |
| Junction 6 | 37.10 | 0.61 |
| Junction 1 | 96.00 | 2.5 |


***Figure 36.*** *Nodes positions.*

## 9.2. Headloss

When water is conveyed through the pipe, hydraulic energy is lost due to the friction between the moving water and the stationary pipe surface. This friction loss is a major energy loss in pipe flow and is a function of flow rate, pipe length, diameter, and roughness coefficient. The head lost to friction associated with flow through a pipe can be expressed in a general fashion as:

$$h_L = aq^b \qquad (10)$$

where:

- $h_L$ = head loss [m],
- q = flow [l/s],
- a = resistance coefficient,
- b = a flow exponent.

For this model, Darcy-Weisbach formula was used as a headloss formula.
Where resistance coefficient, a = 0.0252 f(ε,d,q) $d^{-5}$ L, and flow exponent, b = 2.

- ε = Darcy-Weisbach roughness coefficient, [mm]
- f = friction factor (dependent on ε, d, and q)
- d = pipe diameter, [mm]
- L = pipe length, [m].

### 9.3. Pump curve

In the EPANET softer, pumps are described with a pump characteristic curve.
A pump curve represents the relationship between the head and flow rate that a pump can deliver at its nominal speed setting. Head is the head gain imparted to the water by the pump and is plotted on the vertical (Y) axis of the curve in meters. Flow rate is plotted on the horizontal (X) axis in flow units. A valid pump curve must have decreasing head with increasing flow.

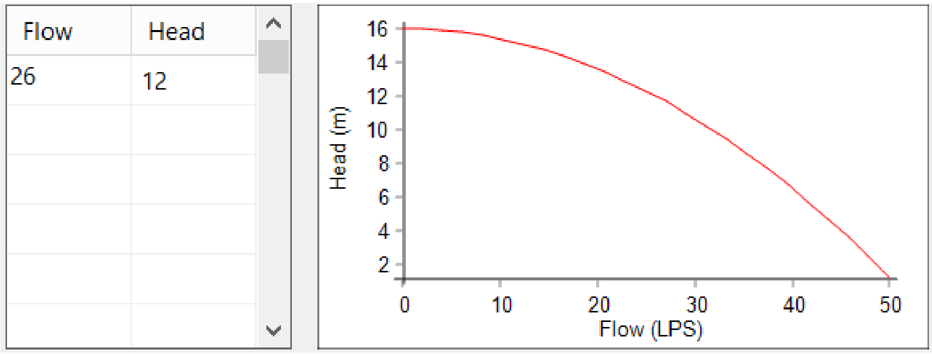


***Figure 37.*** *Pump curve obtained from the EPANET program.*

According to EPANET software equation of the pump curve is as follow:

$$h_G = \frac{8.81 H_p}{q} \qquad (11)$$

where,

- $h_G$ = head gain, [ft]
- $H_p$ = pump [horsepower]
- q = flow, [cfs]

## 9.4. Results

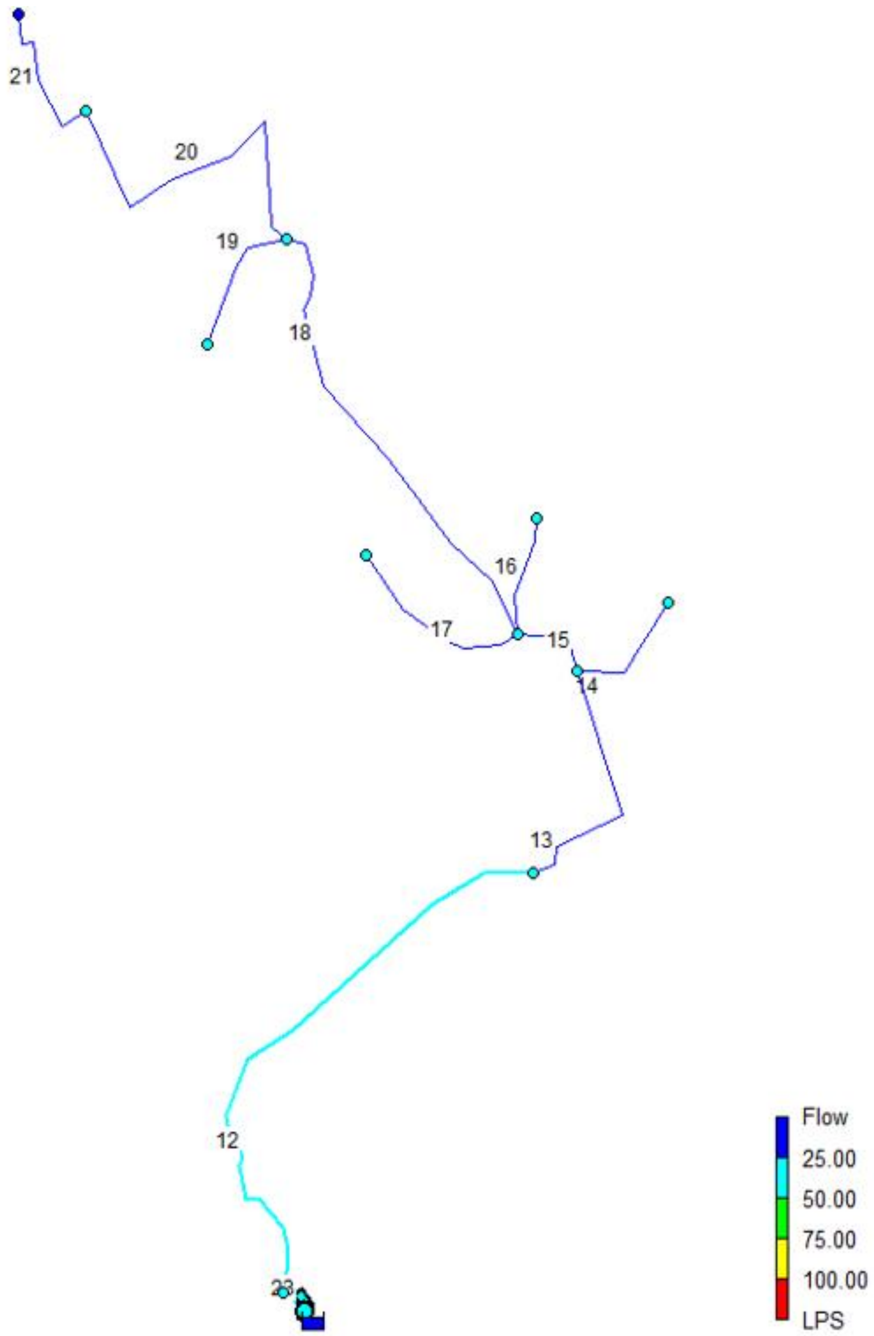


***Figure 38.*** *Pipe network - flow analysis, obtained from the EPANET program.*

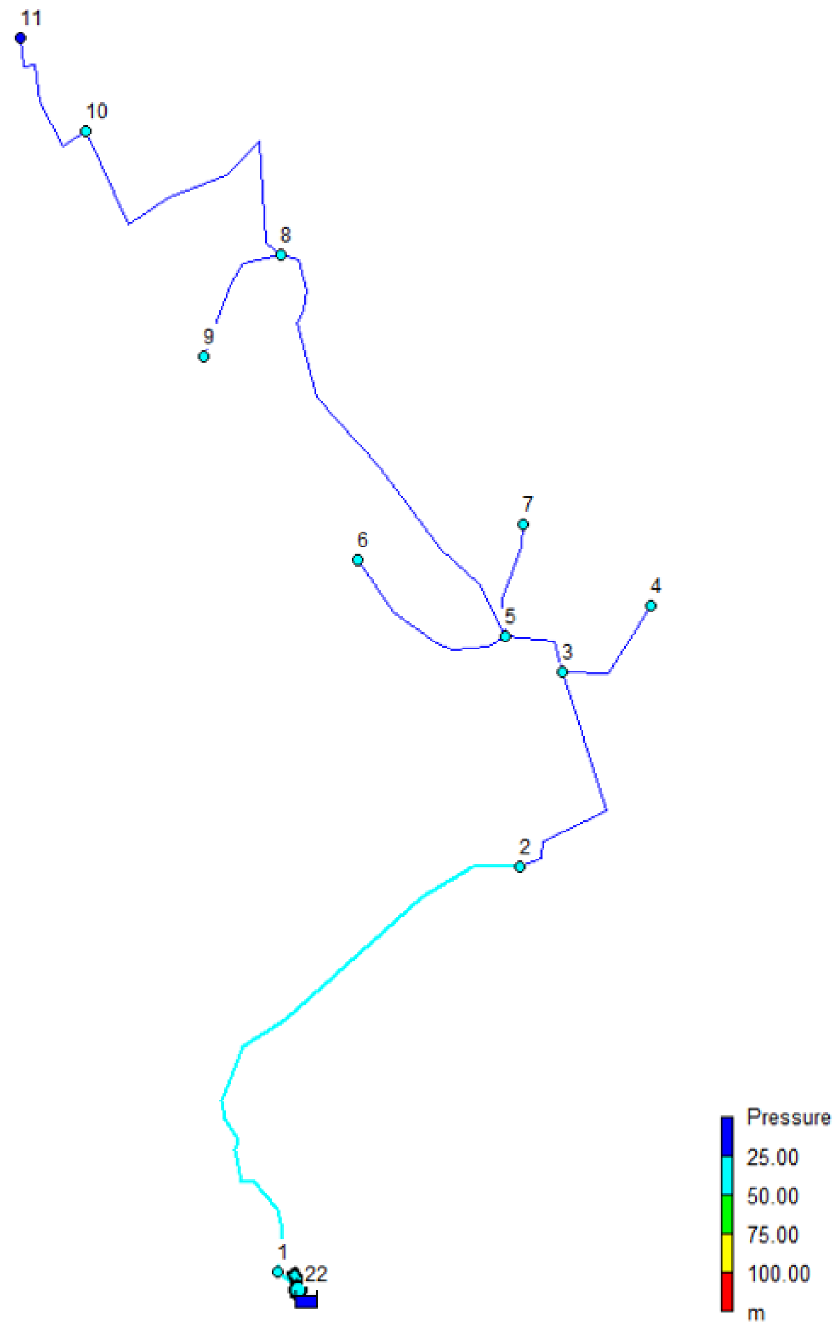


***Figure 39.*** *Pipe network - pressure analysis, obtained from the EPANET program.*

***Table 42.*** *Pressures at nodes, obtained from the EPANET program.*

| Node ID | Pressure [m] | Pressure [bar] |
|---|---|---|
| Junction 11 | 25.35 | 2.54 |
| Junction 10 | 30.18 | 3.02 |
| Junction 3 | 40.01 | 4.00 |
| Junction 4 | 43.75 | 4.38 |
| Junction 5 | 41.70 | 4.17 |
| Junction 8 | 40.33 | 4.03 |
| Junction 7 | 48.85 | 4.89 |
| Junction 2 | 31.98 | 3.20 |
| Junction 9 | 33.96 | 3.40 |
| Junction 6 | 40.41 | 4.04 |
| Junction 1 | 43.81 | 4.38 |

***Table 43.*** *Flow analysis obtained from the EPANET program.*

| Link ID | Flow [l/s] | Headloss [m] | Friction factor |
|---|---|---|---|
| Pipe 21 | 2.41 | 1.25 | 0.026 |
| Pipe 14 | 5.01 | 4.87 | 0.024 |
| Pipe 15 | 15.25 | 1.23 | 0.021 |
| Pipe 18 | 12.17 | 3.40 | 0.021 |
| Pipe 16 | 1.01 | 0.26 | 0.031 |
| Pipe 19 | 3.67 | 2.72 | 0.024 |
| Pipe 20 | 5.32 | 0.73 | 0.024 |
| Pipe 13 | 22.47 | 2.56 | 0.020 |
| Pipe 17 | 0.61 | 0.11 | 0.035 |
| Pipe 12 | 25.23 | 3.18 | 0.019 |

Not all pressures in the system meet values ≥ 3.5 bar, due to this reason, a recommendation can be pressure reducing valve installation before the distribution network integration.

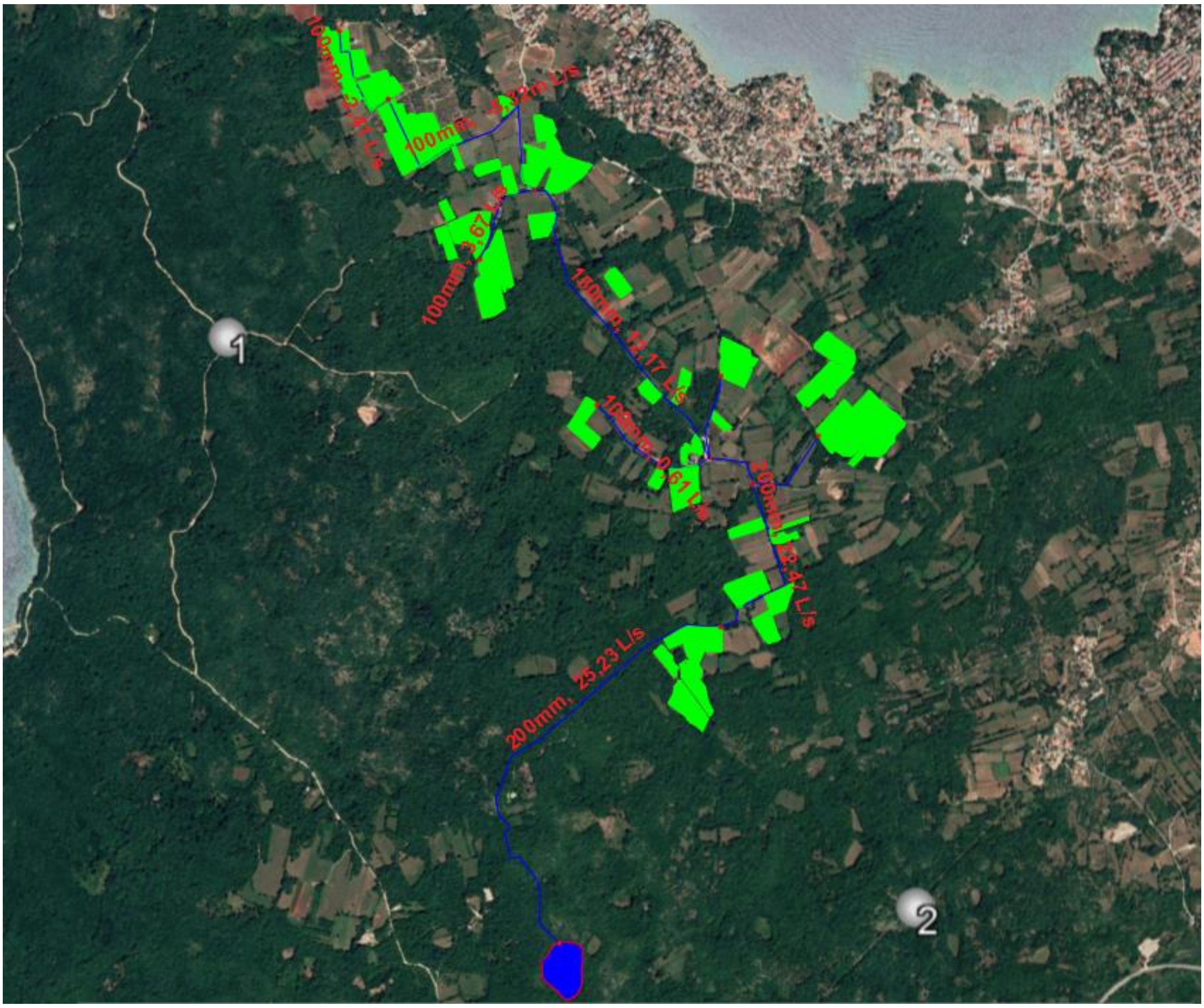


***Figure 40**. The result of the hydraulic analysis for the selected variant.*

The micro-accumulation for a chosen solution is at a sufficient altitude (104 meters above sea level) that the pressures in the system are satisfied for the gravitational water flow. It is still necessary to build a smaller pumping station with a power of 3 kW, in order to overcome the elevated part of the terrain, immediately outside the micro-accumulation.

The diameters of the distribution pipeline and the flows obtained from the EPANET program are shown in Figure 36.

# 10. Approximate cost estimation

Investment costs of the irrigation system Malinska-Dubašnica refer to the costs of projecting, resolving property-legal relations, construction and monitoring system, and connection to the electrical network.

Unit prices of required works are taken from Standard calculations of the works in water management - Bulletin IV 2015, Croatian waters, and defined by comparison with other interventions of this kind.

Costs are calculated for the chosen variant, separately for the micro-accumulation, pumping station, and supply and distribution pipelines. All costs are presented in the Croatian Kuna (HRK), the national currency. The average exchange ratio against euro of the Croatian National Bank on the 10$^{th}$ of June 2020. is 1 euro = HRK 7.569 and is relevant for this Master Thesis. Value Added Tax (VAT), known in Croatia as "PDV" is 25% and is relevant for the purpose of this Master Thesis.

Investment cost of micro-accumulations are defined as follows:

- Construction works as a product of accumulation volume, reference unit prices of construction works 60 HRK / $m^3$ and construction work coefficient.
- The work on the water-resistance of the micro accumulation in the amount of 150 HRK / $m^2$ of the micro-accumulation.
- Craft works as 5% of construction works.
- Unforeseen works as 10% of total works.
- Hydromechanical equipment as 30% of construction works.
- Repurchase of terrain 85 HRK / $m^2$ of accumulation.
- Projecting and supervision as 10% of the value of all works and equipment.

***Table 44.*** *Estimation of investment costs of micro accumulation.*

| **Micro-accumulation costs [HRK]** | **Chosen variant** |
|---|---|
| Volume [$m^3$] | 97.000 |
| Area [$m^2$] | 19.800 |
| Construction work coefficient | 0,25 |
| Construction works | 1.455.000 |
| Water-resistance | 2.970.000 |
| Craft works | 72.750 |
| Unforeseen works | 449.775 |
| Hydromechanical equipment | 436.500 |
| Repurchase of terrain | 1.683.000 |
| Projecting and supervision | 538.403 |
| In total | 7.605.428 |
| VAT | 1.901.357 |
| In total + VAT | 9.506.784 |

Investment costs of pumping station are defined as follows:

- Construction works by comparison with the prices of previous pumping stations of similar purpose and power.
- Craft works as 5% of construction works.
- Unforeseen works as 10% of total works.
- Hydromechanical equipment as 30% of construction works.
- Electrical equipment 1500 HRK / kW pump power.
- Electrical connection network, 2000 HRK / kW pump power.
- Repurchase of terrain, an approximate estimate.
- Projecting and supervision as 10% of the value of all works and equipment.

***Table 45.*** *Estimation of investment costs of pumping station.*

| Costs of pumping station [HRK] | Chosen variant |
|---|---|
| Q [$m^3/s$] | 0,026 |
| H [m] | 12 |
| P [kW] | 3 |
| Construction works | 285.000 |
| Craft works | 14.250 |
| Unforeseen works | 29.925 |
| Hydromechanical equipment | 85.500 |
| Electrical equipment | 4.500 |
| Electrical connection network | 10.000 |
| Repurchase of terrain | 25.000 |
| Projecting and supervision | 42.218 |
| In total | 496.393 |
| VAT | 121.848 |
| In total + V AT | 621.241 |

Investment costs of supply and distribution steel pipelines are defined as follows:

• 700 HRK / m ’ for DN 100 mm

• 850 HRK / m ’ for DN 150 mm

• 1050 HRK / m ’ for DN 200 mm

DN represents nominal diameter of the pipe.

***Table 46.*** *Estimation of investment costs of distribution pipelines.*

| Costs of distribution pipelines [HRK] | Chosen variant |
|---|---|
| **Length [m]** | |
| DN 200 mm | 2393 |
| DN 150 mm | 1138 |
| DN 100 mm | 2698 |
| **Cost [HRK]** | |
| DN 200 mm | 2.512.650 |
| DN 150 mm | 967.300 |
| DN 100 mm | 1.888.600 |
| Unforeseen works | 536.855 |
| Projecting and supervision | 590.541 |
| In total | 6.495.946 |
| VAT | 1.623.986 |
| In total + VAT | 8.119.932 |

***Table 47.*** *Estimation of investment costs of supply pipelines.*

| Costs of supply pipelines [HRK] | Chosen variant |
|---|---|
| **Length [m]** | |
| DN 200 mm | 0 |
| DN 150 mm | 0 |
| DN 100 mm | 901 |
| **Cost [HRK]** | |
| DN 200 mm | 0 |
| DN 150 mm | 0 |
| DN 100 mm | 630.700 |
| Unforeseen works | 63.070 |
| Projecting and supervision | 69.377 |
| In total | 763.147 |
| VAT | 190.787 |
| In total + VAT | 953.934 |

The approximate cost estimation presents the total investment costs of the conceptual project of the irrigation system Malinska-Dubašnica on the island of Krk.
The total investment cost of the conceptual project is 19.201.891 HRK + VAT.

## 10.1. The benefit from the realization of the irrigation system

The benefits from the realization of the irrigation system in the area of question are expressed as an increase in profit from the production of agricultural products, a change in the structure of agricultural production and the implementation of the irrigation system in the area of question.

The basis for calculating the benefits of the project is the calculation of agricultural production per ha for each crop without a project and with the project.

Data on incomes and costs of agricultural production are taken from the Catalog of calculations of agricultural production in 2018, Croatian Agricultural and Forestry Advisory Service.

***Table 48.*** *Share of costs in agricultural production for situations without a project and with the project.*

| Crop | Without a project | | With a project | |
|---|---|---|---|---|
| | Area [ha] | Share of costs [%] | Area [ha] | Share of costs [%] |
| meadow | 25.4 | 84 | - | - |
| potatoes | 3.9 | 53 | 18.6 | 42 |
| cabbage | 0.5 | 43 | 2.5 | 42 |
| tomato | 0.4 | 87 | 1.9 | 58 |
| pepper | 0.6 | 92 | 2.9 | 66 |
| cucumber | 0.2 | 99 | 1.1 | 79 |
| onion | 0.7 | 66 | 3.4 | 56 |
| salad | 0.3 | 70 | 1.2 | 61 |
| watermelon | 0.1 | 70 | 0.5 | 50 |
| Total share of costs | 79 % | | 49% | |

Annual incomes and costs of agricultural production with and without an irrigation project are shown in Table 49. and table 50.

Taking into account the size of agricultural land for growing different crops for the current and planned structure of agricultural production, it can be concluded that the share of costs of the end-user is 30 % higher for the situation without implementing the irrigation project. (Table 48).

***Table 49.*** *Annual incomes and costs of agricultural production with the irrigation project.*

| Crop | Area [ha] | Incomes | | Agricultural production costs | |
|---|---|---|---|---|---|
| | | Income HRK/ha | Incomes [HRK] | Agricultural production and irrigation costs HRK/ha | Agricultural production costs [HRK] |
| potato | 18.6 | 100.000 | 1.860.000 | 41.855 | 778.503 |
| cabbage | 2.5 | 121.429 | 303.571 | 50.566 | 126.415 |
| tomato | 1.9 | 340.000 | 646.000 | 197.727 | 375.681 |
| pepper | 2.9 | 180.000 | 522.000 | 119.485 | 346.506 |
| cucumber | 1.1 | 143.200 | 157.520 | 112.783 | 124.061 |
| onion | 3.4 | 70.000 | 238.000 | 39.320 | 133.688 |
| salad | 1.2 | 150.000 | 180.000 | 90.978 | 109.173 |
| watermelon | 0.5 | 100.000 | 50.000 | 49.921 | 24.960 |
| Total income: | | | 3.957.091 | Total costs: | 2.018.987 |
| Total income + VAT | | | 4.946.363 | | |

***Table 50.*** *Annual incomes and costs of agricultural production without the irrigation project.*

| Crop | Area [ha] | Incomes | | Agricultural production costs | |
|---|---|---|---|---|---|
| | | Income HRK/ha | Incomes [HRK] | Agricultural production costs HRK/ha | Agricultural production costs [HRK] |
| potato | 3.9 | 60.000 | 234.000 | 31.708 | 123.661 |
| cabbage | 0.5 | 85.000 | 42.500 | 36.947 | 18.473 |
| tomato | 0.4 | 187.000 | 74.800 | 163.367 | 65.346 |
| pepper | 0.6 | 108.000 | 64.800 | 99.381 | 59.628 |
| cucumber | 0.2 | 85.920 | 17.184 | 85.294 | 17.058 |
| onion | 0.7 | 42.000 | 29.400 | 27.828 | 19.479 |
| salad | 0.3 | 97.500 | 29.250 | 68.704 | 20.611 |
| watermelon | 0.1 | 55.000 | 5.500 | 38.682 | 3.868 |
| Total income: | | | 497.434 | Total costs: | 328.124 |
| Total income + VAT | | | 621.792 | | |

## 11. Conclusion

The implementation of the conceptual project of the irrigation system at the municipality of Malinska-Dubašnica on the island Krk, with an irrigation area of 32 ha includes, the construction of a micro-accumulation with the pumping station, distribution pipelines, and pipelines for water supply.

The total investment costs of the conceptual project, which include electrical connection network, repurchase of land, construction, projecting, and supervision is 15.363.913 HRK without VAT and 19.201.891 HRK + VAT.

Taking into account the size of agricultural land for growing different crops for the current and planned structure of agricultural production, the share of end-user costs is 30% higher for the situation without the implementation of the irrigation project.

The total annual profit from the implementation of the irrigation project Malinska Dubašnica is 2,633,708 HRK higher than without the irrigation project. It can be concluded that the construction of the irrigation project Malinska Dubašnica is acceptable.

Recommendations for further work on the project implementation are primarily data processing of surveyed local users in order to define the final agricultural areas for irrigation. After that, it is possible to start preparing project documentation and obtaining the necessary permits.

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