LIFE14 CCA/GR/000389 - AgroClimaWater
Promoting water efficiency and supporting the shift towards a climate resilient agriculture in Mediterranean countries

Sub-Deliverable C2.1: Water Availability in LIFE AgroClimaWater Pilot sub –basins in Crete

Action C2: Identification and assessment of water efficiency in the three F.ORs - Before LIFEAgroClimaWater

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Terminology / Abbreviations

Term	Description
ASCE	American Society of Civil Engineers
EMY	National Meteorological Service
G.Y.S	Hellenic Military Geographical Service

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1. INTRODUCTION

The main aim of this deliverable is the estimation of the renewable water resources of the pilot areas of LIFE AgroClimaWater project in Crete, Greece (Tavronitis River Basin in the Municipality of Platanias and Havgas-Milatos river basin in the Municipality of Agios Nikolaos, Fig. 1 and Fig. 2) in dry, medium and wet conditions.

1.1. Methodology

The renewable water resources in the areas of interest are assumed to be equal to the infiltrated/percolated water since only the groundwater is exploited for several water uses within these areas. The infiltrated water in wet, medium and dry conditions was estimated through the calculation of the parameters of water balance in the respective hydrological conditions.
The water balance of a river basin is calculated through an equation that quantifies the inputs and losses of water of a catchment area. The calculation of the water balance is based on data relating to the main hydrological data of the catchment area.
The general equation of the water balance represents the balance between the inputs (precipitation) and the outputs (surface runoff, evapotranspiration and infiltration) within an area over a long period of time, as shown in the following equation:

$$P = E + R + \Delta Sa \qquad \text{(Eq. 1)}$$

where:
P : is the amount of precipitation (rainfall, show etc),
E : is the evapotranspiration,
R : is the surface runoff,
ΔSa : is the shift of the groundwater during the same period of time. This change is usually equal to the infiltration of water into the ground.
ΔS is the storage in the soil, *aquifers* or reservoirs (SSWM)

Calculation of input (precipitation)
The volume of water that precipitates in the pilot areas is calculated by using the rainfall data derived from the meteorological stations presented in paragraphs 2.2 and 2.3 and the total area of the targeted catchment area.

Calculation of outputs
Evapotranspiration, runoff and infiltration are the components that comprise the outputs.

Evapotranspiration is calculated from the classical empirical method of Turc (1954):

$$E_P = \frac{P}{\sqrt{0{,}90 + \left(\frac{P}{L}\right)^2}} \text{ (mm/ month)} \qquad \text{(Eq. 2)}$$

where:
Ep : is the average annual evapotranspiration in mm,

P : the average annual rainfall in mm,
L : temperature function given by the following equation:

$$L=300+25T+0,05T3 \quad \text{(Eq. 3)}$$

where:
T : is the average annual temperature in Celsius.

Moreover, taking into account that Turc method is a simplified – generalized method, which uses just the precipitation and temperature, we assume that the evapotranspiration that is calculated by the Turc method incorporates the infiltration (component ΔSa of Eq. 1). Thus, the evapotranspiration hereafter is called "flow deficit" since except for the net evapotranspiration we assume that it includes the shift of ground water (ΔSa).

Infiltration is estimated by the "flow deficit" that is calculated according to Turc method minus the net evapotranspiration that is calculated according to Hargreaves – Samani (1985) method, as proposed by the "ASCE Standardized Reference Evapotranspiration Task Committee Appendix A", combined with the crop factor method. By the latter method, the net evapotranspiration is calculated taking into account not only the temperature and precipitation, but also the incident ray at the boundary of the atmosphere (extraterrestrial radiation), the type of crops and the crop coefficient. Therefore, the crop factor method is more accurate for the estimation of net evapotranspiration than with Turc Method.

Having calculated the "flow deficit" for dry, mean and wet hydrological conditions and the net evapotranspiration according to Turc and Hargreaves – Samani methods, respectively, the difference between them (Turc "flow deficit" minus Hargreaves – Samani evapotranspiration) gives the estimated quantity of the water volume that is infiltrated in the aquifers annually in dry, mean and wet hydrological conditions.

1.2. Area description

In this study the water balance in Tavronitis (Fig. 1) and Havgas - Milatos (Fig. 2) Basin was estimated. As far as the Tavronitis basin is concerned the water balance was estimated for the entire basin (including the two pilot basins of Platanias) with the exception of the grey area which is presented in Fig. 1. The reason is that this area is considered as an autonomous, independent catchment basin and as it was out of the scope of this study it was excluded from the calculations.

Fig. 1: Geodatabase Map Extract of Tavronitis River basin (blue outline) and Voukolies (brown outline) and Maleme pilot sub-basins (black outline)

According to the "Special Water Resources Management Plan" of Tavronitis basin (Technical University of Crete, 2012), Tavronitis is one of the largest rivers in western Crete. Its basin is located twenty (20) kilometres west of Chania city, has a rectangular shape and its area is almost 146 sq.km.

Tavronitis basin significantly contributes in the formation of water resources in the general area of the Prefecture of Chania. The hydrographic network of Tavronitis River begins from Lefka Ori at the altitude of 1,400m and discharges into the Sea of Crete. Its basin is consisted of three (3) main sub-basins of:

A) Sebroniotis tributary, which flows from Sebronas village.
B) Roumatianos tributary, which flows from Palaia Roumata village and
C) Derianos tributary, the springs of which are located at Prasses village.

The first two (2) tributaries, are joined together upstream near Voukolies village, where the main riverbed of Tavronitis River is formed. The Derianos tributary is discharged at Syrili village, where it joins the main riverbed of Tavronitis three (3) kilometres before it discharges into the sea.

In the wider catchment area of Tavronitis River Basin the terrain varies significantly between 1,400m altitude in the southern part (foothills of Lefka Ori) and 0m in the northern part (coastline), where Tavronitis River discharges into the sea. The southern part of the basin is part of the Lefka Ori massif. In this section the hydrographic network is very thin with deeply gulleys and minimal vegetation. The intermediate part is mountainous and hilly with dense river network and richer vegetation, while the northern part is flat with thick vegetation and dense river network.

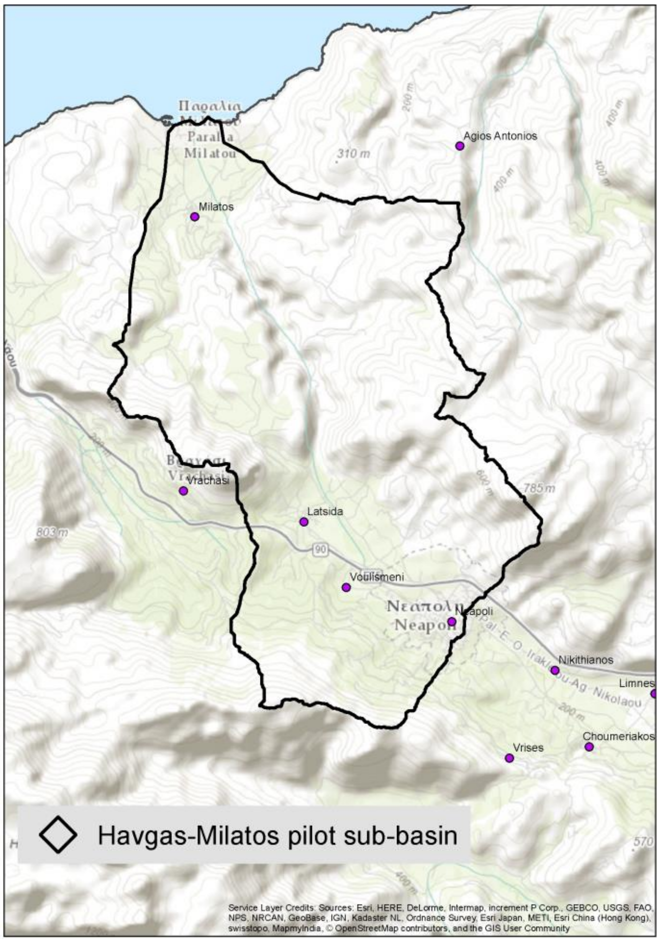

Fig. 2: Geodatabase Map Extract of Havgas-Milatos pilot sub-basin

The Havgas – Milatos River Basin is smaller than that of Tavronitis River Basin. Specifically, the basin covers an area of 29 sq.km. The maximum altitude of the basin is 900m, the minimum is 0m and the basin abuts the Sea of Crete. The hydrographic network of the area is not very dense. According to the available topographic maps of the Hellenic Military Geographical Service (G.Y.S.) scaled 1:50,000 and more specifically the map entitled "Agios Nikolaos", there is no visible named river or stream.

For the calculation of the water balance, meteorological data from meteorological stations that are included both in the study area and in broader areas around the basins are required. Specifically, the values of mean, maximum and minimum annual rainfall are necessary, as the water balance will be calculated annually but in different hydrological conditions (wet, dry and mean). Moreover, for the calculation of flow deficit according to Turc method, the mean annual air temperature is required (°C).

2. "FLOW DEFICIT"

2.1. Meteorological Data

Aiming at the estimation of the water balance, the meteorological data from stations that are within the study areas, as well as in the wider area are required. Specifically, the values of maximum, average and minimum annual rainfall are necessary, as water balance is estimated for different hydrological conditions (wet, mean and dry) in an annual base. Furthermore, the average annual air temperature (°C) is required for the calculation of the "flow deficit" by the Turc method.

2.2. Tavronitis basin

In Tavronitis basin, the meteorological stations of Prases and Palaia Roumata, which are located in the mountain range, within the catchment area of Tavronitis, were selected. These stations are supervised by the Department of Hydroeconomy of Crete. Due to its terrain, it was necessary to take into account the meteorological data also from coastal stations. For this reason, data from the coastal meteorological stations of Souda and Rethymno, which are operated by the National Meteorological Service (E.M.Y.), were used.
Since Maleme basin is located in the lowland area, only the data from the coastal stations of Souda and Rethymno were taken into account. In the Turc method the annual meteorological data, temperature and rainfall, were taken into account.
The available data of the meteorological stations that are used for the water balance estimation are the following:

- Station Palaia Roumata – Altitude +316m
  1. Monthly rainfall data from year 1960 until 2009
- Station Prases – Altitude +520m
  1. Monthly rainfall data from year 1960 until 2009
- Station Souda – Altitude +148m
  1. Daily rainfall data from year 1958 until 2015
  2. Daily average temperature data from year 1958 until 2015
- Station Rethymno – Altitude +18m
  3. Daily rainfall data from year 1957 until 2004
  4. Daily average temperature data from year 1957 until 2004

2.2.1. Rainfall Data

In order to estimate the water balance in wet, medium and dry conditions it was necessary maximum, average and minimum annual rainfall to be respectively calculated. For this reason, the daily data of rainfall of the pre-mentioned weather stations were processed and the results are presented in Table 1.

Table 1: Average, maximum and minimum annual rainfall data

Station	Rainfall (mm)		
	Average	**Maximum**	**Minimum**
Palaia Roumata	1,315.79	2,200.00	639.70
Prases	1,793.01	2,855.30	1,182.50
Souda	630.18	978.20	297.20
Rethymno	637.67	911.10	299.20

As previously indicated, the meteorological stations of Prases and Palaia Roumata are located in the mountainous part of Tavronitis basin and therefore represent the mountainous meteorological sample data. On the other hand, the meteorological stations of Souda and Rethymno represent the coastal meteorological sample data. Due to the location of the mountainous stations (both of them are within the catchment area and roughly in the same area) a 50% degree of influence was selected for each station. Hence, their values for the average, maximum and minimum annual rainfall represent the mountainous region values and they are presented in Table 2.
Accordingly, the calculation of the average, maximum and minimum annual rainfall of the coastal stations (Souda and Rethymno) was required. Souda station is located almost 20km away from Tavronitis basin (centre of the lowland part of Tavronitis basin), while Rethymno station is located around 60km away. Consequently, Souda station was chosen as a lowland station with an influence degree of 67%, while Rethymno station with an influence of 33%.
Moreover, for the calculation of the annual rainfall it was necessary the estimation of average, maximum and minimum rainfall of Tavronitis basin taking into account both lowland and mountainous values. The total area of Tavronitis basin is almost 145.87 sq.km. The area of Platanias pilot sub-basins can be characterized as lowland, with an area of around 33.24 sq.km, while the rest 112.63 sq.km of Tavronitis basin is considered to be a mountainous area. In conclusion, the lowland area covers 22.79% of the Tavronitis basin, while the mountainous area covers the rest 77.21%.
The average, maximum and minimum rainfall for the total area of Tavronitis basin is also presented in Table 2.

Table 2: Average, maximum and minimum annual rainfall in Tavronitis basin.

Area	Rainfall/precipitation (mm)		
	Average	Maximum	Minimum
Mountainous area	1,554.40	2,527.65	911,10
Lowland area	632.66	956.06	297.79
Total area	1,344.33	2,169.48	771.33

2.2.2. Temperature Data

Considering the lowland meteorological stations' temperature data, the average annual temperature for Souda (18.42°C) and Rethymno station (19.66°C) was calculated. Using the influence degree that was mentioned during the rainfall calculation (67% for Souda and 33% for Rethymno) the average temperature was calculated to be equal to 18.83°C.
As far as the mountainous area is concerned, there were no available temperature data for neither of the mountainous stations (Prasses and Palaia Roumata). As a result, an assessment of the average temperature of the mountainous stations was made taking into account the scientific book "Lessons on Meteorology and Climatology", A. Flokas (1997).
According to Flokas (1997) the rate of the temperature variation with the increase in height is expressed with the vertical lapse rate. This is defined as the decrease of air temperature in a height unit. Symbolising it with γ, we have:

$$\gamma = -\frac{\partial T}{\partial z} \quad \text{(Eq. 4)}$$

The minus sign (-) indicates that an increase of height causes a reduction in temperature (in the troposphere). 100m or 1km is usually used as a height unit, meaning that γ is expressed in °C/100m or °C/km. The lapse rate in the troposphere is expressed as:

γ=0,6 °C/100m or γ=6 °C/1km

Assuming that, the lapse rate is a constant value Eq. 4 after the integration becomes:

$$T_{(z)} = T_{(z_0)} - \gamma(z - z_0) \quad \text{(Eq. 5)}$$

Where $T_{(z)}$ and $T_{(z_0)}$ is the air temperature at height Z and Z_0, respectively. By using this equation it is possible to calculate the value of the air temperature at the height Z, when the corresponding temperature value is known at height Z_0.

Taking into account the influence degree of each station, the reference altitude of the lowland stations is equal to $Zo=H_{lowlan}=0.67\times148+0.33\times18=105.10$m and of the mountainous stations is $Z=H_{mount}=(316+520)/2=418$m. Therefore, the estimated temperature of the mountainous stations is 16.95°C. The annual temperature for Tavronitis basin was calculated using the same assumption that was used for the annual rainfall (influence degree of 22.79% for the lowland stations and 77.21% for the mountainous stations). Therefore, the final average annual temperature for Tavronitis basin was equal to 17.38°C (Table 3).

Table 3: Annual Temperature in Tavronitis basin.

Area	Temperature (°C)
Mountainous area	16.95
Lowland area	18.83
Total area	17.38

2.3. Havgas-Milatos sub-basin

In Havgas – Milatos sub-basin, the meteorological station of Neapoli Lasithiou, which is located within the basin, was selected. This station is supervised by the Department of Hydroeconomy of Crete. Because of its terrain, it was necessary to take into account also the meteorological data from lowland stations. Thus, the data from Irakleio meteorological station, which is supervised by the National Meteorological Service (E.M.Y.), was also used.

The available data of the meteorological stations that were used for the calculation of water balance are the following.

- Station Neapoli Lasithiou – Altitude +240m
    1. Monthly rainfall data from year 1932 until 2012
- Station Irakleio – Altitude +39m
    1. Daily rainfall data from year 1955 until 2015
    2. Daily average temperature data from year 1955 until 2015

2.3.1. Rainfall Data

In order to estimate the water balance in wet, mean and dry conditions, it was necessary to calculate the average, maximum and minimum annual rainfall. For this purpose, the daily data of these stations were processed in order to extract the pre-mentioned values. The results for each station are presented in Table 4.

Table 4: Average, maximum and minimum annual rainfall data for Havgas-Milatos catchment area

Station	Rainfall (mm)		
	Average	Maximum	Minimum
Neapoli Lasithiou	817.02	1,296.50	411.50
Irakleio	477.43	493.90	261.80

The next step was the calculation of the average, maximum and minimum annual rainfall of Havgas – Milatos sub-basin. Taking into account the fact that the influence of both stations was 50%, the final average, maximum and minimum rainfall was calculated and the results are presented in Table 5.

Table 5: Average, maximum and minimum annual rainfall for Havgas – Milatos sub-basin

Rainfall of Havgas – Milatos sub-basin (mm)	
Average annual rainfall	647.22
Maximum annual rainfall	1,045.20
Minimum annual rainfall	336.65

2.3.2. Temperature Data

According to the meteorological station of Irakleio, the average annual temperature was 18.92°C. Due to the fact that the meteorological station of Neapoli Lasithiou did not provide any temperature records the average temperature was estimated using the lapse rate according to the scientific book of A. Flokas. The altitudes of Irakleio Station (39m) and Neapoli Lasithiou station (240m) were used as reference and target height, respectively. The estimated temperature for Neapoli Lasithiou station was calculated at 18.32°C.

2.4. Water balance by Turc Method

Table 6 represents the results of the water balance calculation in mean, dry and wet conditions for Tavronitis basin using the Turc method. According to Turc method the evapotranspiration represents the sum of net evapotranspiration and infiltration and is named as “flow deficit”.

Table 6: Annual water balance for mean, dry and wet conditions for Tavronitis basin.

Annual Water balance	HYDROLOGICAL CONDITIONS		
	DRY	MEAN	WET

Basin area (Sq.km)=	145,87	145,87	145,87
Average precipitation (mm)=	771,33	1.344,33	2.169,48
Average Temperature °C =	17,38	17,38	17,38
L coefficient=	996,99	996,99	996,99
Evapotranspiration according to Turc (mm)=	630,09	815,40	913,92
Flow deficit (mm)=	630,09	815,40	913,92
Runoff (mm)=	141,23	528.93	1.255,57
Runoff coefficient=	18,31%	39,35%	57,87%
Non-runoff coefficient=	81,69%	60,65%	42,13%
Non-runoff volume (m^3)=	91.911.154,43	118,941,555.28	133.312.115,45
Runoff volume (m^3)=	20.601.736,58	77,154,710.57	183.148.651,23

In order to calculate the mean, wet and dry conditions of the pilot area, the values that are presented in Table 6 are multiplied with the influence degree of the pilot area, which is 22.79% of the total area of Tavronitis. The non-runoff volume in mean, wet and dry hydrological conditions in the pilot area of Voukolies and Maleme sub-basins are presented in Table 7.

Table 7 Non-runoff volume in Voukolies and Maleme sub-basins

Hydrological conditions	**Non-runoff volume (m^3)=**
Mean	**27,106,780.45**
Dry	**20,946,552.10**
Wet	**30,381,831.11**

Table 8 represents the results of the calculated water balance calculated for Havgas – Milatos sub-basin.

Table 8: Annual water balance for mean, dry and wet conditions for Havgas – Milatos sub-basin

Annual Water balance	**HYDROLOGICAL CONDITIONS**		
	DRY	**MEAN**	**WET**
Basin area (Sq.km)=	29,09	29,09	29,09
Average precipitation (mm)=	336,65	647,22	1.045,20
Average Temperature °C =	18,32	18,32	18,32
L coefficient=	1.065,43	1.065,43	1.065,43
Evapotranspiration according to Turc (mm)=	336,68	574,54	765,89
Flow deficit (mm)=	336,68	574,54	765,89
Runoff (mm)=	-0,03	72,69	279,31
Runoff coefficient=	0,00%	11,23%	26,72%
Non-runoff coefficient=	100,00%	88,77%	73,28%
Non-runoff volume (m^3)=	9.794.354,89	16.715.364,91	22.282.395,66
Runoff volume (m^3)=	0,00	2.114.677,90	8.126.217,84

3. EVAPOTRANSPIRATION AND THE CROP FACTOR METHOD

3.1. Reference crop evapotranspiration

The method that was used for the calculation of the reference evapotranspiration of grass was the Hargreaves – Samani method (1985). The Hargreaves – Samani method consists of an equation, which uses only the temperature as input parameter. However, while the method takes into account only the solar radiation, its results approaches with sufficient accuracy the results of the Pennman – Monteith method, which is the most accurate method for the calculation of reference crop evapotranspiration.
As proposed by ASCE (2005), the Hargreaves – Samani method is based on the difference between maximum and minimum temperature, the average daily temperature and the solar radiation outside the atmosphere. The reference crop evapotranspiration is calculated according to the following equation:

$$ET_0 = 0.0023 \cdot R_a \cdot (T_m + 17.8) \cdot (T_{max} - T_{min})^{0.5} \qquad \text{(Eq. 6)}$$

Where:

ET_0:	Reference crop evapotranspiration in mm/day
T_m:	average daily temperature in °C,
T_{max}:	maximum daily temperature in °C,
T_{min}:	minimum daily temperature in °C,
R_a:	the incident ray at the boundary of the atmosphere (extraterrestrial radiation) in mm/day.

Ra value is calculated according to Duffie and Beckman (1980, 1991) by using the following equation:

$$R_a = \frac{1440}{\pi} G d_r \left[\omega_s \sin(\phi)\sin(\delta) + \cos(\phi)\cos(\delta)\sin(\omega_s)\right] \qquad \text{(Eq. 7)}$$

Where:

G:	is the solar constant (0,082 MJ sq.m/min)
dr:	is the reversed relative distance of earth from the sun
φ:	is the latitude
ωs:	is the angle of the sunset (rad),
δ:	is the angle of the solar deviation (rad)

As the unit of Ra is in MJ/sq.m/day, a conversion to mm/day is needed, according to the following equation:

$$mm/day = MJ/sq.m/day/2.43 \qquad \text{(Eq. 8)}$$

3.2. Meteorological Data

As it was previously mentioned, the available data of the meteorological stations that were used for the evapotranspiration calculation are the following:

- Station Souda – Altitude +148m

1. Daily average, max and min temperature data from year 1958 until 2015

- Station Rethymno – Altitude +18m

1. Daily average, max and min temperature data from year 1957 until 2004

- Station Irakleio – Altitude +39m

1. Daily average, max and min temperature data from year 1955 until 2015

The difference between the evapotranspiration calculated by Turc method and the evapotranspiration calculated by Hargreaves – Samani method is that in the first methodology annual meteorological data are required, while in the second one monthly data are used.

During the data processing, the same influence degrees that were used in Turc method were also used for the calculations in Hargreaves – Samani method.

3.3. Crops evapotranspiration or crop water needs

The crop evapotranspiration differs distinctly from the reference evapotranspiration (ET_0) as the ground cover, canopy properties and aerodynamic resistance of the crop are different from grass. The effects of the characteristics that distinguish field crops from grass are integrated into the crop coefficient (K_c).

In the crop coefficient approach the crop evapotranspiration, ET_C, is calculated by multiplying the reference crop evapotranspiration, ET_0, by a crop coefficient, K_c:

$$ET_C = K_C * ET_0 \quad \text{(Eq. 9)}$$

Where:

ETc: crop evapotranspiration in mm/day,

Kc: crop coefficient (dimensionless),

ET_0: reference crop evapotranspiration in mm/day.

Because reference ET_0 represents nearly all effects of weather, K_c varies predominately with specific crop characteristics and only a small amount with climate. This enables the transfer of standard values for K_c between locations and climates.

The types of crops cultivated in the pilot areas were identified according to Corine Landcover 2000. This estimation was considered to be acceptable for the purpose of the study.

Within Tavronitis pilot sub-basins, the main cultivation categories are:

- Olive groves (23.1 sq.km)
- Fruit trees and berry plantations (4 sq.km), which are mainly consisted of orange trees
- Complex cultivation patterns (2.55 sq.km), which are mainly consisted of animal feeding/fodder crops (Medicago disciformis).

In Havgas – Milatos sub-basin, two (2) cultivation categories are mainly presented:

- Olive groves (10.93 sq.km)
- Complex cultivation patterns (1.56 sq.km), which are mainly consisted of animal feeding/fodder crops (Medicago disciformis).

The crop factors (K_c) that is used in this study, derived either from the relative bibliography (FAO bulletin 56, Tsanis et al., 1997) or experimental data that were available for Crete and were modified by the research team of IOTSP in the project BEWARE (2002-2005) according to the data that were collected for tree cultivation in the areas of Messara (Prefecture of Heraklion) and the plain of Chania (which include the pilot areas). The crop factors for each crop are presented in Table 10 to Table 12 in next paragraph.

4. RESULTS

4.1. Voukolies and Maleme pilot sub-basins

Table 9 to Table 12 presents the reference evapotranspiration and the net crop evapotranspiration that has been calculated by the Hargreaves – Samani method, as explained in previous paragraphs for Voukolies and Maleme pilot sub-basins.

Table 9: Reference crop evapotranspiration for Voukolies and Maleme pilot sub-basins

Reference Evapotranspiration						
Months	**Number of Days**	**T_{avg} °C**	**T_{max} °C**	**T_{min} °C**	**Ra mm/day**	**Et_r mm/day**
January	31	11.62	14.77	8.46	7.53	1.28
February	28	11.69	15.04	8.32	9.50	1.67
March	31	13.31	16.84	9.45	12.18	2.37
April	30	16.35	20.18	11.84	14.73	3.34
May	31	20.41	24.42	15.20	16.43	4.39
June	30	24.84	28.71	19.08	17.18	5.23
July	31	26.89	30.52	21.34	16.73	5.21
August	31	26.58	30.33	21.45	15.43	4.69
September	30	23.67	27.57	19.07	13.18	3.66
October	31	19.93	23.73	16.05	10.65	2.56
November	30	16.30	19.93	12.86	8.13	1.70
December	31	13.34	16.54	10.17	6.75	1.22

Table 10: Olive grove evapotranspiration for Voukolies and Maleme Pilot sub-basins

Month	**Days**	**K_c**	**ET_c (mm)**	**Month ET_c (mm)**
January	31	0.00	0.00	0.00
February	28	0.00	0.00	0.00
March	31	0.00	0.00	0.00
April	30	0.35	1.17	35.06
May	31	0.30	1.32	40.78
June	30	0.30	1.57	47.05
July	31	0.35	1.82	56.51
August	31	0.42	1.97	61.11

September	30	0.48	1.76	52.74
October	31	0.50	1.28	39.68
November	30	0.00	0.00	0.00
December	31	0.00	0.00	0.00

Table 11: Orange grove evapotranspiration for Voukolies and Maleme Pilot sub-basins

Month	Days	K_c	ET_c (mm)	Month ET_c (mm)
January	31	0.00	0.00	0.00
February	28	0.00	0.00	0.00
March	31	0.00	0.00	0.00
April	30	0.75	2.50	75.13
May	31	0.75	3.29	101.95
June	30	0.75	3.92	117.62
July	31	0.72	3.75	116.24
August	31	0.69	3.24	100.40
September	30	0.66	2.42	72.51
October	31	0.65	1.66	51.59
November	30	0.00	0.00	0.00
December	31	0.00	0.00	0.00

Table 12: Medicago disciformis evapotranspiration for Voukolies and Maleme pilot sub-basins

Month	Days	K_c	ET_c (mm)	Month ET_c (mm)
January	31	0.00	0.00	0.00
February	28	0.00	0.00	0.00
March	31	0.00	0.00	0.00
April	30	0.00	0.00	0.00
May	31	1.22	5.35	165.84
June	30	1.32	6.90	207.01
July	31	1.33	693	214.72
August	31	1.32	6.20	192.06
September	30	1.33	4.87	146.12
October	31	0.00	0.00	0.00
November	30	0.00	0.00	0.00
December	31	0.00	0.00	0.00

According to the above tables and the relevant areas per cultivated crop that are presented in paragraph 3.3, the total water needs/evapotranspiration for each kind of crop are:

- Olive groves: 7,690,519.26m^3
- Orange groves: 2,541,738.81m^3
- Medicago disciformis: 2,360,661.42m^3

- **Total evapotranspiration: 12,592,919.48m³**

4.2. Havgas - Milatos pilot sub-basin

Table 13 to Table 15 present the reference evapotranspiration and the net crop evapotranspiration that were calculated according to Hargreaves – Samani method, as it was explained in previous paragraphs, for Havgas - Milatos pilot sub-basin.

Table 13: Reference crop evapotranspiration for Havgas - Milatos pilot sub-basin

	Days	T_{avg} ºC	T_{max} ºC	T_{min} ºC	Ra mm/day	Et_r mm/day
January	31	12.15	15.34	9.13	7,58	1,30
February	28	12.26	15.58	8.96	9,54	1,70
March	31	13.63	16.98	9.85	12,21	2,36
April	30	16.61	20.13	12.06	14,74	3,31
May	31	20.41	23.61	15.12	16,44	4,21
June	30	24.46	27.31	19.26	17,17	4,74
July	31	26.40	28.95	21.91	16,74	4,51
August	31	26.31	28.83	22.09	15,44	4,07
September	30	23.75	26.67	19.55	13,21	3,37
October	31	20.30	23.59	16.76	10,67	2,44
November	30	16.79	20.23	13.64	8,18	1,67
December	31	13.82	17.06	10.89	6,81	1,23

Table 14: Olive grove evapotranspiration for Havgas - Milatos Pilot sub-basin

Month	Days	K_c	ET_c (mm)	Month ET_c (mm)
January	31	0.00	0.00	0.00
February	28	0.00	0.00	0.00
March	31	0.00	0.00	0.00
April	30	0.35	1.16	34.79
May	31	0.30	1.26	39.15
June	30	0.30	1.42	42.62
July	31	0.35	1.58	48.97
August	31	0.42	1.71	52.93
September	30	0.48	1.62	48.50
October	31	0.50	1.22	37.87
November	30	0.00	0.00	0.00
December	31	0.00	0.00	0.00

Table 15: Medicago disciformis evapotranspiration for Havgas -Milatos Pilot sub-basin

Month	Days	K_c	ET_c (mm)	Month ET_c (mm)
January	31	0.00	0.00	0.00

February	28	0.00	0.00	0.00
March	31	0.00	0.00	0.00
April	30	0.00	0.00	0.00
May	31	1.22	5.14	159.22
June	30	1.32	6.25	187.54
July	31	1.33	6.00	186.10
August	31	1.32	5.37	166.34
September	30	1.33	4.48	134.38
October	31	0.00	0.00	0.00
November	30	0.00	0.00	0.00
December	31	0.00	0.00	0.00

According to the above tables and the relevant areas per cultivated crop that are presented in paragraph 3.3 (page 17), the total water needs for each kind of crop are:

- Olive groves: 3,331,881.81m^3
- Medicago disciformis: 1,300,379.60m^3
- **Total evapotranspiration: 4,632,261.41m^3**

5. ANNUAL INFILTRATION – RENEWABLE WATER

As it has already been mentioned, the water infiltrates in the aquifers was the only water source that was used in both areas. Therefore, the infiltrated water in wet, mean and dry hydrological conditions is assumed to be the renewable water volume of the project’s pilot sub basins.

According to the analysis of the previous paragraphs, the annual infiltration is the difference between the flow deficit (Turc method) and the water needs by crops in the area of interest (Net evapotranspiration by Hargreaves – Samani and crop factor methods). The annual infiltration in wet, mean and dry hydrological conditions for Voukolies and Maleme sub-basins and Havgas – Milatos are presented in Table 16 and Table 17, respectively.

Table 16: Infiltration of Voukolies and Maleme sub-basins

Infiltration of Tavronitis basin (m^3)	
Minimum annual infiltration	8,353,632.62
Mean annual infiltration	14,513,860.97
Maximum annual infiltration	17,788,911.63

Table 17: Infiltration of Havgas – Milatos sub-basin

Infiltration of Havgas – Milatos sub-basin (m^3)	
Minimum annual infiltration	5,162,093.48
Mean annual infiltration	12,083,103.50
Maximum annual infiltration	17,650,134.25

6. IRRIGATION NEEDS OF COPS

As it was mentioned in previous chapters, the reference crop evapotranspiration was calculated according to Hargreaves – Samani method, and then it was multiplied with the crop factor, for each crop and for each month of the year so that the net evapotranspiration of each crop to be calculated.

In order to identify the irrigation needs for each crop, the average monthly effective rainfall was calculated and deducted from the crops' total water requirement (net evapotranspiration).

During the calculation of crops' water needs, rainfall is also a crucial factor. The effective rainfall is the part of the rainfall that inflows the root zone and is used by the crops for their development. The effective rainfall depends on a number of factors, among the most important of which are:

- The amount and the intensity of rainfall
- The storage capacity in the route zone of the plants
- The condition of the grounds surface (dry soil, tree foliage)
- Water filtration in the group
- The moisture deficit prior to rainfall that is determined by the moisture status (irrigated areas) and
- Evaporation

After determining the amount of rainfall by meteorological data as described in paragraphs 2.2 (page 11) and 2.3 (page 14), the effective rainfall, which was used in the determination of the irrigation water needs of the crops was estimated empirically. According to an empirical formula, the amount of effective rainfall R_e, is calculated according to the following equation:

$$P_e = \left[P - \left(c + \frac{P}{8}\right)\right] \qquad \text{(Eq. 10)}$$

Where:

P : is the total monthly precipitation P≥7, [mm]

c : is an empirical constant with values ranging from 10 (for lowland and coastal areas) untill 20 (for inland and mountainous regions). For the studied area the selected value is 10 [-].

The calculations mentioned above are summarised in the following tables for Tavronitis (Table 18) and Havgas – Milatos (Table 19) basins.

Table 18: Effective rainfall based for Tavronitis basin

Month	Precipitation	Effective Rainfall
January	128.94	102.82
February	110.51	86.69
March	76.30	56.76
April	32.32	18.28
May	14.74	2.90
June	3.82	0.00
July	0.88	0.00

Month	Precipitation	Effective Rainfall
August	1.84	0.00
September	17.02	4.90
October	71.89	52.90
November	77.72	58.01
December	107.84	84.36

Table 19: Effective rainfall based for Havgas – Milatos sub-basin

Month	Precipitation	Effective Rainfall (Empirical)
January	123.92	98.43
February	97.72	75.50
March	75.41	55.99
April	38.05	23.29
May	17.49	5.31
June	5.59	0.00
July	1.27	0.00
August	1.25	0.00
September	18.99	6.61
October	71.91	52.92
November	81.19	61.04
December	114.91	90.54

Finally, the effective rainfall is deducted from the evapotranspiration of each crop, and the result is the net Irrigation need of each crop in mm per 1,000 sq.m.
The results are shown in the tables:

Table 20: Irrigation need for Tavronitis basin

Water needs in mm per 1,000 sq.m			
Month	Olive Groves	Orange Groves	Medicago disciformis
January	0.00	0.00	0.00
February	0.00	0.00	0.00
March	0.00	0.00	0.00
April	16.78	56.85	0.00
May	37.88	99.06	162.95
June	47.05	117.62	207.01
July	56.51	116.24	214.72
August	61.11	100.40	192.06
September	47.84	67.62	141.22
October	0.00	0.00	0.00
November	0.00	0.00	0.00
December	0.00	0.00	0.00

Table 21: Irrigation need for Havgas – Milatos basin

Water needs in mm per 1,000 sq.m		
Month	**Olive Groves**	**Medicago disciformis**
January	0.00	0.00
February	0.00	0.00
March	0.00	0.00
April	11.50	0.00
May	33.84	153.91
June	42.62	187.54
July	48.97	186.10
August	52.93	166.34
September	41.89	127.77
October	0.00	0.00
November	0.00	0.00
December	0.00	0.00

According to the above tables and the cultivation areas of crops, the total water need for irrigation of crops in the pilot areas is:

Irrigation need for Voukolies and Maleme pilot areas:

- Olive groves: 6,171,526.67m^3
- Orange groves: 2,231,090.10m^3
- Medicago disciformis:2,340,791.01m^3
- **Total demand: 10,743,407.78m^3**

Irrigation need for Mirabello pilot area:

- Olive groves: 2,533,005.95m^3
- Medicago disciformis: 1,281,781.90m^3
- **Total demand: 3,814,787.84m^3**

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