# Development of the hydrologic balance of a basin using the real evapotranspiration rate

**K. GUDULAS**[1], **K. VOUDOURIS**[1, 2], **G. SOULIOS**[1, 2] **& G. DIMOPOULOS**[1, 2]

1 *Department of Pollution Control Technologies, Technological Educational Institute of West Macedonia, Kozani 50100, Greece*

2 *Department of Geology, Aristotle University of Thessaloniki, Thessaloniki 54006, Greece*

kgudulas@otenet.gr

**Abstract** The assessment of the hydrologic balance of a water basin represents a critical parameter that is often used for the rational utilization of the water resources of the surrounding area. In this work, the hydrologic balance was developed for the study area that included two lakes in Northern Greece: lake Zazari and lake Cheimaditida. The basin of the two lakes covers an area of 228 km$^2$ and it is part of the greater closed basin of lake Vegoritida, located in the region of West Macedonia, in Greece. The objective of this work was the detailed estimation of the hydrologic balance of the water basin, by using the Thornthwaite method for the calculation of the evapotranspiration factor, and the comparison to the Turc approach. For the calculation of the evapotranspiration, the data of temperature and rain over a period over of thirty years were collected and used. The implementation of the Turc method results to the real evapotranspiration rate; however, the application of Thornthwaite equation seems more beneficial as the maximum potential evapotranspiration may be calculated. Using this method, and by the application of a certain methodology, the monthly predicted evapotranspiration rate and the corresponding real one may be estimated. The hydrologic balance of an area may be calculated by the estimation of the percentage of the rain that will result to draining and infiltration, in addition to the evapotranspiration parameter. These factors, i.e. draining and infiltration may be deduced by the geological and hydro-geological data of the area and the corresponding land uses. For the particular basin, the Thornthwaite equation, for medium temperatures, gave a real evapotranspiration rate of ET=412.4 mm (80.2%) for P=514.4mm and a draining rate of Q=102mm (19.8%). In addition, the estimation of the corresponding rates for maximum temperature gave a value of ET=83,8%, while for the minimum temperature the corresponding value was about 67.4%. However, the Turc equation gave a slight higher results i.e. ET=428,8 mm for medium temperatures, ET=483.5 mm for maximum and ET= 353.9 mm for minimum temperatures.

**Keywords** hydrologic balance; real evapotranspiration; Turc method; Thornthwaite equation

## INTRODUCTION

Actual Evapotranspiration, ETa, is one of the most useful indicators to explain the rationalized use of water resources in an area. Spatial and time ETa variations, from different land use applications (particularly from irrigated lands), are considered as efficient indications of the adequacy, reliability and equity in water use; the knowledge of these terms is essential for judicious water resources management. Unfortunately, ETa estimation under actual field conditions is still a very challenging task for scientists and water managers. The complexity associated with the estimation of ET has lead to the development of various methods for estimating this parameter over time Doorenbos & Pruitt (1977) and Allen et al (1998).

Several models have been proposed by scientists, which are taking into account only the parameter of potential evapotranspiration and do not consider the real effective evapotranspiration such as the Penman equation, the Haude and the Thornweite.

In this work, the total hydraulic balance of an area is estimated by the calculation of the monthly potential evapotranspiration (PET), the monthly real active evapotranspiration (ETa), and the fraction of rainfall corresponding to infiltration and draining.

## STUDY REGION AND DATA

The study area includes the hydrologic basin of two lakes in Greece, lake Zazari and Chimatidida. Lake Chimatidida includes a Watergate in the area of Rodona. The total surface of the target land is about 228 km2; about 34,7 km2 is the surface of the Chimatidida sub-basin, while 98,4 km2 is the surface of the Zazari lake subbasin. The surface of the first lake is 9,5 km2 and the corresponding surface of the latter one is 1,9 km2, as shown in Figure 1.

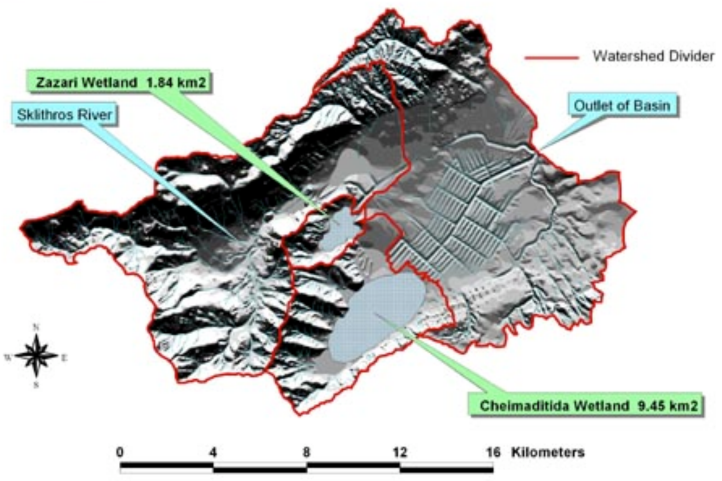

Figure 1 **Diagram of the study basin.**

This hydrologic basin is part of the greater basin of Vegoritida lake. The target basin is located on the south-eastern part of Florina prefecture. The Chimatidida lake is about 1.5 km from the settlement of Anargiroi, while lake Zazari is close to Limnoxori.

The hydrologic network of the basin is consisting of a number of small length torrents, which are discharged directly to the lakes or are diluted in the neighbouring sediments: torrents Sklithro, Fanoremma and Amintas that is discharged to the Petron lake Figure 2. Papadimos and Katsavouni (2007).

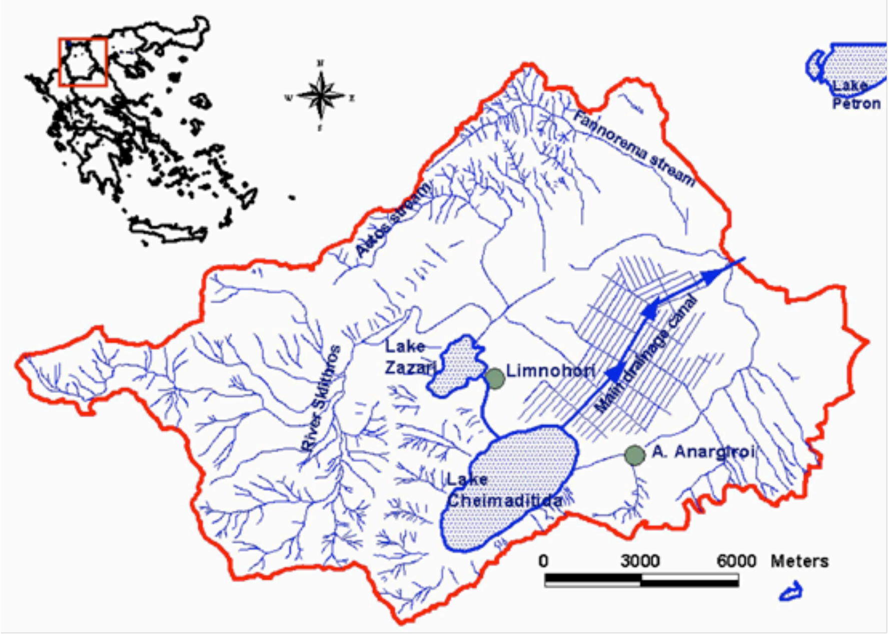

Figure 2 **Graphical representation of the hydrological basin.**

In the greater area there have been installed since 1964, 11 meteorological stations Figure 3. The meteorological station that was used in this work for the estimation of evapotranspiration rate is the station of Limnochori, inside the study area, which was used as the background for the homogenization and normalization of the data. This station is located at latitude of 21034΄N and a longitude of 40038΄E. Several hydro meteorological variables, including air temperature, wind speed, relative humidity, solar radiation, vapour pressure, and evaporation, among others, have been continuously recorded for the period 1996 to 1998.

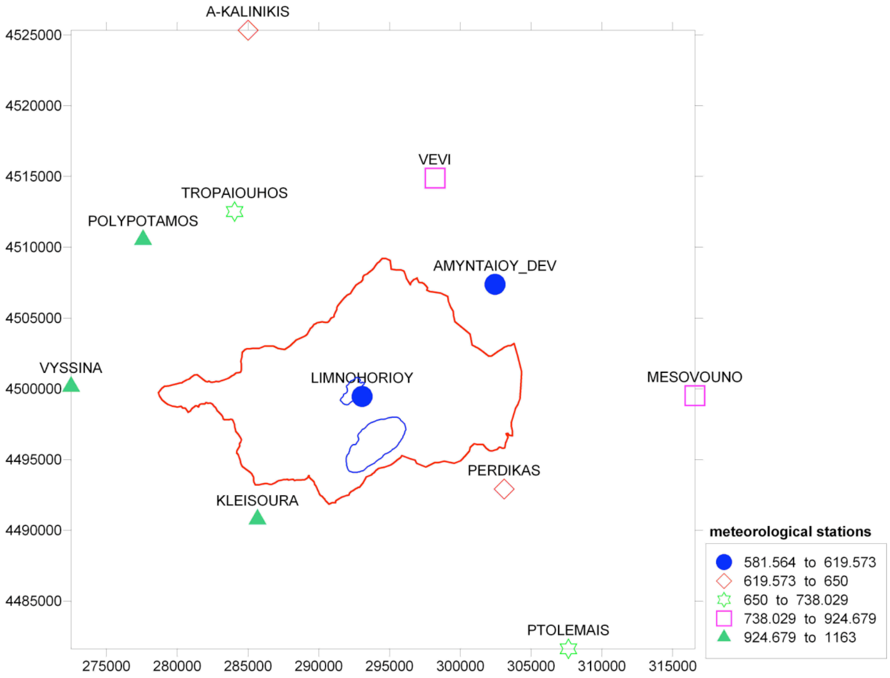

Figure 3 **Location of the meteorological stations in the study area.**

The study area has a climate type different from the climatic conditions of the Greek Mediterranean type, due to the high altitude (600-1900 m) and the long distance from the sea side. In addition, as the target area is close to the continental mainland, and there are not any mountains in the northern side, the climatic conditions are similar to the middle-european type.

The summer season is warm with maximum temperatures on July, while winter is cold with minimum temperatures during January. Spring frosts are often extended till the end of April, while the snow period starts on November and sometimes is prolonged till April.

## Area geologic information

The area of the lakes belongs to the Pelagonic geotectonic zone and is located in the southeastern part of the greated hydrologic basin of Vegoritida. This zone is extended from north-northwestern to north-northeastern and starts from the borders between Greece and FYROM up to the Magnesia peninsula and the Skiathos and Skopelos islands (Mountrakis, 1985). Is is consisted of Paleozoic and pre-Paleozoic metamorphic rocks, on which neogene and quaternary sediments have been developed.

The whole Zazari lake and the southwestern part of the Chimaditida lake have been developed in the background of these metamorphic rocks (gneiss, amphibolitic and slates), which are water impermeable structures In a distance of about 2.5-3 km northeastern from the Chimaditida lake, and close to the draining ditch, slates have been found in three wells, in depths of 419, 425 and 489 m respectively. However, in a longer distance from the lake to the northeastern side, in the cetre of the basin, similar background was not found in wells with depths exceeding 500 m.

In addition to these minerals, in different locations to the eastern and north eastern side of Chimaditida lake, carbonate minerals were found, below the neogene background from the Mesozoic Era in various depths in 5 wells. These minerals were found in depths ranging from 135 to 435 m. Limestone was found in two wells in depths 413 and 435 m respectively, in a distance of 3.7 km and 2.4 km northeastern from the lake. In lower depths (130-170 m) these minerals were found in an area in the eastern side from the settlement of Anargiroi in about 5 km from the northeastern bank of the lake Chimaditida.

Between the impermissible substrate of the metamorphic rocks and the bottom of the lakes, the neogene sediments are inserted, which have been developed as a result of the physical weathering of the neighboring mountainous structures.

## Estimation of the Potential Enapotranspiration rate (PET) by the Thornthweite equation

Thornthwaite (1948) proposed an empirical method to estimate the potential evapotranspiration from mean temperature data. The method uses air temperature as an index of the energy available for evapotranspiration, assuming that air temperature is correlated with the integrated effects of net radiation and other controls of evapotranspiration, and that available energy is shared. The Thornthwaite equation is given below:

$$PE = 16 * \left(10 \frac{T}{I}\right)^{a} \qquad (1)$$

where

PE is the monthly potential evapotranspiration,

T is the monthly mean air temperature (°C),

I is a heat index for the station which is the sum of 12 monthly heat indices

$$I = \sum_{n=1}^{n=12} i_n = \sum_{n=1}^{n=12} \left(\frac{T}{5}\right)^{1.514} \qquad (2)$$

i given by $i = \left(\frac{T}{5}\right)^{1.514}$ and (3)

a is a cubic function of I

$$a = 6.75 * 10^{7} * I^{3} - 7.71 * 10^{5} * I^{2} + 1.79 * 10^{2} * I + 0.4923 \qquad (4)$$

Both a and I can be found from tables, e.g. Thornthwaite & Mather (1957).

This method of computing the monthly water balance was revised and summarized by Thornthwaite & Mather (1957) to make it more useful over a wide range of soils and vegetations. In order to determine the water balance at a site it is necessary to have the following specific information:

a) latitude,
b) mean monthly air temperature,
c) mean monthly precipitation,
d) necessary conversion and computation tables,
e) information on the water-holding capacity of the depth of soil for which the balance is to be computed.

By the application of the Thornthwaite equation as modified by Dimopoulos (1979), the results given in Table 1 may be deduced for the average values of temperatures.

Average monthly temperatures are given in row 1, in Table 1, calculated from the daily values over a period of 30 years. The monthly Heat Index i is shown in row, estimated by equation (3), while the Heat Factor I calculated by equation (2) is given in row 3. The average potential transpiration from equation 1 is given in row 4, while the correction factor for the certain area latitude is presented in row 5 (latitude = 40°). The normalized evaporotranspiration PETn=PET*n is shown in row 6, the anerage monthly precipitates in row 7, and the change of water reserves used by plants in row 8. The available water reserves are equal to 100 mm water column. The water amount available for vegetation is given in row 9. The water loss from ground surface due to moisture reduction, APWL, is given in row 10. APWL is negligible when precipitates are higher than PET, otherwise it is estimated by the addition of the previous month APWL to the negative value of (P-PET). Ground humidity is presented in row 11, while in row 12, ΔSt corresponds to the ground water monthly change. The actual evapotranspiration is calculated in row 13, the WD=PETn-Eta in row 14 while values in row 15 represent Q and are calculated using the following: If Ew>0 then Q=Ew-ΔSt and if Ew=0 then Q=0

Table1 **Water Balance Mean Monthly Temperatures**

**WATER BALANCE**

Temperatures in °C. water-balance terms in mm.

| **Month:** | **J** | **F** | **M** | **A** | **M** | **J** | **J** | **A** | **S** | **O** | **N** | **D** | **Year** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T | 2.60 | 3.80 | 6.60 | 11.3 | 15.9 | 19.8 | 22.00 | 21.60 | 18.10 | 13.50 | 7.90 | 4.50 | 12.30 |
| i | 0.37 | 0.66 | 1.52 | 3.44 | 5.76 | 8.03 | 9.42 | 9.16 | 7.01 | 4.50 | 2.00 | 0.85 | |
| I | | | | | | | | | | | | | 52.74 |
| PET | 6.3 | 10.4 | 21.5 | 43.8 | 68.7 | 91.8 | 105.6 | 103.0 | 81.6 | 55.4 | 27.3 | 13.0 | 628.4 |
| n | 0.84 | 0.83 | 1.03 | 1.11 | 1.24 | 1.25 | 1.27 | 1.18 | 1.04 | 0.96 | 0.83 | 0.81 | |
| PETn | 5.3 | 8.6 | 22.2 | 48.6 | 85.2 | 114.8 | 134.1 | 121.6 | 84.8 | 53.2 | 22.6 | 10.5 | 711.5 |
| P | 37.0 | 38.4 | 44.4 | 41.3 | 54.5 | 22.1 | 21.8 | 29.5 | 24.4 | 51.5 | 88.4 | 61.1 | 514.4 |
| Uw | 0.0 | 0.0 | 0.0 | 7.3 | 30.7 | 92.7 | 112.3 | 92.1 | 60.4 | 1.7 | 0.0 | 0.0 | |
| Ew | 31.7 | 29.8 | 22.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 65.8 | 50.6 | |
| APWL | 0.0 | 0.0 | 0.0 | -7.3 | -38.0 | -130.8 | -243.0 | -335.1 | -395.5 | -397.2 | 0.0 | 0.0 | |
| St | 100.0 | 100.0 | 100.0 | 93.0 | 68.4 | 27.0 | 8.8 | 3.5 | 1.9 | 1.9 | 67.7 | 100.0 | |
| ΔSt | 0.0 | 0.0 | 0.0 | -7.0 | -24.6 | -41.3 | -18.2 | -5.3 | -1.6 | 0.0 | 65.8 | 32.3 | |
| ETa | 5.3 | 8.6 | 22.2 | 48.3 | 79.1 | 63.4 | 40.0 | 34.8 | 26.0 | 51.5 | 22.6 | 10.5 | 412.4 |
| WD | 0.0 | 0.0 | 0.0 | 0.3 | 6.1 | 51.4 | 94.0 | 86.8 | 58.9 | 1.7 | 0.0 | 0.0 | 299 |
| Q | 31.7 | 29.8 | 22.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 18.3 | 102.0 |

T= Mean Monthly Temperature
i= Monthly heat index
I= Heat index
PET= Potential Evapotranspiration.
n= Amplitude index= 40°
PETn= Normalized Potential Evapotranspiration
P= Monthly Precipitation
Uw= Deficiency Water
Ew= Excess Water for vegetation
APWL= The water loss from ground surface due to moisture reduction
St=Soil Moisture
ΔSt=Change in Soil Moisture
ETa= Actual Evapotranspiration
WD= Water Deficiency
Q= Drainage

Table 2 **Hydrologic Balance for average temperatures**

| | P= | ET | + | Q |
|---|---|---|---|---|
| % | 100 | 80.2 | | 19.8 |
| mm | 514.4 | 412.4 | | 102.0 |
| $m^3$ | 117283200.0 | 94027210.7 | | 23255989.3 |

## Estimation of the hydrologic balance of the area

The surface of the target area is $F=228\ Km^2$, the annual precipitated water volume is given by:

$V=P*F$ (5)

where P is the average annual precipitation rate (514.4 mm). Thus,

$V== 117283200\ m^3$

The annual precipitation in the area is $117283200\ m^3$ of water column. From this amount, about 412.4 mm of water column corresponded to the evapotranspiration and thus the real annual evapotraspiration in the area is:

$V_1 =ETa *F=94027210\ m^3$

As a result from a total of $117283200\ m^3$ precipitated in the area, about $94027210\ m^3$ are evapotranspirated through the plants, while the residual amount, Ue=P-ETa, i.e. $23255989.3\ m^3$ corresponds to the infiltration (I) and the drainage (A), representing 102 mm of water column. Consequently, the hydrologic balance equation of the area is

$P=ET+I+R$ (6)

$P=ET+Q$ (7)

By the application of the Thornthwaite equation as modified by Dimopoulos (1979), the following results may be deduced for the maximum and minimum values of temperatures. Specifically the results for the maximum temperatures are shown in the following Table 3 and 4, while the corresponding data for the minimum temperatures are given in Table 5 and 6.

**Table 3** Water Balance for the average maximum temperatures

**WATER BALANCE**

Temperatures in $^{o}$C. water-balance terms in mm.

| **Month:** | **J** | **F** | **M** | **A** | **M** | **J** | **J** | **A** | **S** | **O** | **N** | **D** | **Year** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T | 7 | 8.6 | 11.8 | 17.2 | 22.5 | 26.9 | 29.2 | 29.1 | 25.2 | 20.5 | 13.1 | 9.2 | 18.36 |
| i | 1.66 | 2.27 | 3.67 | 6.49 | 9.75 | 12.78 | 14.47 | 14.39 | 11.57 | 8.47 | 4.30 | 2.52 | |
| I | | | | | | | | | | | | | 92.34 |
| PET | 9.1 | 13.9 | 26.3 | 56.2 | 96.6 | 138.6 | 163.6 | 162.5 | 121.5 | 80.1 | 32.4 | 15.9 | 916.7 |
| n | 0.84 | 0.83 | 1.03 | 1.11 | 1.24 | 1.25 | 1.27 | 1.18 | 1.04 | 0.96 | 0.83 | 0.81 | |
| PETn | 7.7 | 11.5 | 27.0 | 62.4 | 119.8 | 173.3 | 207.8 | 191.7 | 126.4 | 76.9 | 26.9 | 12.9 | 1044.2 |
| P | 37.0 | 38.4 | 44.4 | 41.3 | 54.5 | 22.1 | 21.8 | 29.5 | 24.4 | 51.5 | 88.4 | 61.1 | 514.4 |
| Uw | 0.0 | 0.0 | 0.0 | 21.1 | 65.3 | 151.2 | 186.0 | 162.2 | 102.0 | 25.4 | 0.0 | 0.0 | |
| Ew | 29.3 | 26.9 | 17.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 61.5 | 48.2 | |
| APWL | 0.0 | 0.0 | 0.0 | -21.1 | -86.4 | -237.6 | -423.5 | -585.8 | -687.7 | -713.1 | 0.0 | 0.0 | |
| St | 100.0 | 100.0 | 100.0 | 81.0 | 42.1 | 9.3 | 1.4 | 0.3 | 0.1 | 0.1 | 61.6 | 100.0 | |
| ΔSt | 0.0 | 0.0 | 0.0 | -19.0 | -38.9 | -32.8 | -7.8 | -1.2 | -0.2 | 0.0 | 61.5 | 38.4 | 0.0 |
| ETa | 7.7 | 11.5 | 27.0 | 60.3 | 93.4 | 54.9 | 29.6 | 30.7 | 24.6 | 51.5 | 26.9 | 12.9 | 431.0 |
| WD | 0.0 | 0.0 | 0.0 | 2.1 | 26.5 | 118.3 | 178.1 | 161.0 | 101.8 | 25.4 | 0.0 | 0.0 | |
| Q | 29.3 | 26.9 | 17.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 9.8 | 83.4 |

Table 4 **Hydrologic Balance for average maximum temperatures**

| | P= | ET + | Q |
|---|---|---|---|
| % | 100 | 83.8 | 16.2 |
| mm | 514.4 | 431.0 | 83.4 |
| m$^3$ | 117283200.0 | 98267627.6 | 19015572.4 |

**Table 5** Water Balance for the average minimum temperatures

**ATER BALANCE**

Temperatures in $^{o}$C. water-balance terms in mm.

| **Month:** | **J** | **F** | **M** | **A** | **M** | **J** | **J** | **A** | **S** | **O** | **N** | **D** | **Year** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T | -1.90 | -1.10 | 1.40 | 5.40 | 9.20 | 12.70 | 14.80 | 14.10 | 10.90 | 6.50 | 2.80 | -0.30 | 6.21 |
| i | 0.00 | 0.00 | 0.15 | 1.12 | 2.52 | 4.10 | 5.17 | 4.80 | 3.25 | 1.49 | 0.42 | 0.00 | |
| I | | | | | | | | | | | | | 23.02 |
| PET | 0.0 | 0.0 | 10.4 | 33.6 | 53.5 | 70.9 | 81.0 | 77.7 | 62.1 | 39.5 | 19.0 | 0.0 | 447.8 |
| n | 0.84 | 0.83 | 1.03 | 1.11 | 1.24 | 1.25 | 1.27 | 1.18 | 1.04 | 0.96 | 0.83 | 0.81 | |
| PETn | 0.0 | 0.0 | 10.7 | 37.3 | 66.4 | 88.6 | 102.9 | 91.7 | 64.6 | 38.0 | 15.8 | 0.0 | 515.9 |
| P | 37.0 | 38.4 | 44.4 | 41.3 | 54.5 | 22.1 | 21.8 | 29.5 | 24.4 | 51.5 | 88.4 | 61.1 | 514.4 |
| Uw | 0.0 | 0.0 | 0.0 | 0.0 | 11.9 | 66.5 | 81.1 | 62.2 | 40.2 | 0.0 | 0.0 | 0.0 | |
| Ew | 37.0 | 38.4 | 33.7 | 4.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 13.5 | 72.6 | 61.1 | |
| APWL | 0.0 | 0.0 | 0.0 | 0.0 | -11.9 | -78.4 | -159.6 | -221.7 | -261.9 | 0.0 | 0.0 | 0.0 | |
| St | 100.0 | 100.0 | 100.0 | 100.0 | 88.8 | 45.6 | 20.3 | 10.9 | 7.3 | 20.8 | 93.5 | 100.0 | |
| ΔSt | 0.0 | 0.0 | 0.0 | 0.0 | -11.2 | -43.1 | -25.4 | -9.4 | -3.6 | 13.5 | 72.6 | 6.5 | |
| ETa | 0.0 | 0.0 | 10.7 | 37.3 | 65.7 | 65.2 | 47.2 | 38.9 | 28.0 | 38.0 | 15.8 | 0.0 | 346.8 |
| WD | 0.0 | 0.0 | 0.0 | 0.0 | 0.7 | 23.4 | 55.8 | 52.8 | 36.6 | 0.0 | 0.0 | 0.0 | 169 |
| Q | 37.0 | 38.4 | 33.7 | 4.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 54.6 | 167.6 |

Table 6 **Hydrologic Balance for average minimum temperatures**

| | P= | ET + | Q |
|---|---|---|---|
| % | 100 | 67.4 | 32.6 |
| mm | 514.4 | 346.7603428 | 167.6396572 |
| m$^3$ | 117283200.0 | 79061358.2 | 38221841.8 |

As a result, estimation of the real evapotranspiration may take place by the application of the modified Thornthwaite – Mather method in the target basin. According to this method, the potential evapotranspiration may be calculated initially and then the real effective one.

In order to justify the use of the Thornthwaite – Mather method, the results that have been calculated by this method will be compared to the corresponding results from the Turc equation (1951). The models that have been proposed for the estimation of the real evapotranspiration are based on the precipitation rate P, while the models for potential evapotranspiration are taking into account the temperature factor. The Turc equation is given in the following:

$$E = \frac{P}{\sqrt{0.9 + \frac{P^2}{L^2}}} \qquad (8)$$

Where E is a real annual evapotranspiration, mm

P is the precipitation height, mm

$$L = 300 + 25T + 0.05 * T^3 \qquad (9)$$

The temperature factor used in this equation is the average air temperature in °C, which represents the evaporation capacity of the air.(Soulios 1986)

Application of the Turc method for P=514.4 mm and at a T=12.3 $^{o}$C, results to the following value of ET=428.8mm. In addition, the application of this method for the maximum and minimum temperature values will give:

Max avgT= 18.4 oC ET=483.5 mm and Min avgT= 6.2 oC ET=353.9 mm

The monitoring data from a number of 254 basins, worldwide, were similar to the the results estimated by using the Turc equation. This model is best applied at precipitates higher than 700 mm. It has also been suggested that *T* should be replaced by the corrected temperature $T_c$, which takes into account the annual distribution of precipitation over the course of air temperature in the formula 10.

$$T_c = \frac{P_1 * T_1 + P_2 * T_2 ... + P_{12} * T_{12}}{P_1 + P_2 + .. P_{12}} \qquad (10)$$

The results given in Tables 7, 8 and 9 will be calculated for average, maximum and minimum temperatures respectively.

**Table 7** Turc Equation corrected for Average temperatures

| | J | F | M | A | M | J | J | A | S | O | N | D | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P | 37.0 | 38.4 | 44.4 | 41.3 | 54.5 | 22.1 | 21.8 | 29.5 | 24.4 | 51.5 | 88.4 | 61.1 | 514.4 |
| T= | 7.0 | 8.6 | 11.8 | 17.2 | 22.5 | 26.9 | 29.2 | 29.1 | 25.2 | 20.5 | 13.1 | 9.2 | 18.4 |
| Tc | 259.0 | 330.2 | 523.9 | 710.4 | 1226.3 | 594.5 | 636.6 | 858.5 | 614.9 | 1055.8 | 1158.0 | 562.1 | 16.6 |
| L= | 942.6 | | | | | | | | | | | | |
| ET= | 470.0 | | | | | | | | | | | | |

**Table 8** Turc Equation corrected for Maximum temperatures

| | J | F | M | A | M | J | J | A | S | O | N | D | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P | 37.0 | 38.4 | 44.4 | 41.3 | 54.5 | 22.1 | 21.8 | 29.5 | 24.4 | 51.5 | 88.4 | 61.1 | 514.4 |
| T= | 7.0 | 8.6 | 11.8 | 17.2 | 22.5 | 26.9 | 29.2 | 29.1 | 25.2 | 20.5 | 13.1 | 9.2 | 18.4 |
| Tn | 259.0 | 330.2 | 523.9 | 710.4 | 1226.3 | 594.5 | 636.6 | 858.5 | 614.9 | 1055.8 | 1158.0 | 562.1 | 16.6 |
| L= | 942.6 | | | | | | | | | | | | |
| ET= | 470.0 | | | | | | | | | | | | |

**Table 9** Turc Equation corrected for Minimum temperatures

| | J | F | M | A | M | J | J | A | S | O | N | D | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P | 37.0 | 38.4 | 44.4 | 41.3 | 54.5 | 22.1 | 21.8 | 29.5 | 24.4 | 51.5 | 88.4 | 61.1 | 514.4 |
| T= | -1.9 | -1.1 | 1.4 | 5.4 | 9.2 | 12.7 | 14.8 | 14.1 | 10.9 | 6.5 | 2.8 | -0.3 | 6.2 |
| Tn= | -70.3 | -42.2 | 62.2 | 223.0 | 501.4 | 280.7 | 322.6 | 416.0 | 266.0 | 334.8 | 247.5 | -18.3 | 4.9 |
| L= | 428.5 | | | | | | | | | | | | |
| ET= | 336.2 | | | | | | | | | | | | |

The results estimated by the application of the two equations have been collected in Table 10. As shown, the values calculated by the two methods are similar, with the Turc equation resulting in slightly higher values.

**Table 10** Comparative equations Turc and Thornthwaite

| | TURC | | THORNTHWAITE | | |
|---|---|---|---|---|---|
| | ET | $ET_n$ | PET | $PET_n$ | ET |
| Tmin | 353.9 | 336.2 | 447.8 | 515.9 | 346.8 |
| Tavg | 428.8 | 411.3 | 628.4 | 711.5 | 412.4 |
| Tmax | 483.5 | 470.0 | 916.7 | 1044.2 | 431.O |
| P=514.4 mm | | | | | |

## CONCLUSIONS

The aim of this work was the estimation of the real evapotranspiration in a basin consisting of two lakes, in Northern Greece, by the use of the modified Thornthwaite method. The Thornthwaite equation was applied for the calculation of the Potential Evapotranspiration rate, based on the average monthly real evapotranspiration, and taking into account the average monthly precipitation rate and the corresponding water reserves required for plant development. The excess or deficient water may be calculated for each month and can be used in the water balance equation.

For the particular basin, the Thornthwaite equation, for medium temperatures, gave a real evapotranspiration rate of ET=412.4 mm (80.2%) for P=514.4mm and a draining rate of Q=102mm (19.8%). In addition, the estimation of the corresponding rates for maximum temperature gave a value of ET=83,8%, while for the minimum temperature the corresponding value was about 67.4%. However, the Turc equation gave a slight higher results i.e. ET=428,8 mm for medium temperatures, ET=483.5 mm for maximum and ET= 353.9 mm for minimum temperatures.

By comparison of the Turc method with the the Thornthwaite, it can be concluded that although the Turc equation is simpler than the latter for the estimation of the real evapotranspiration, the calculated values are slightly higher than the Thornthwaite ones. In general results estimated for the Greek basins are higher, but for the particular basin both models give similar values.

By the application of the Turc equation using the corected temperature, an Evapotranspiration value is calculated which is similar to the corresponding estimated by the Thornthwaite equation; for the minimum Tn the evapotranspiration value is lower, while for maximum $T_c$ this value is higher than the Thornthwaite value.

## REFERENCES

Allen RG, Pereira LS, Raes D, Smith M (1998) Crop evapotranspiration guidelines for computing crop water requirements. FAO *Irrigation & Drainage* Paper 56. FAO, Rome

Dimopoulos, G. (1979): Calculation the real Evapotranspiration and hydrologic balance of basin with Thornthweite method, *Ann.Fac. Phys. & Mathem.*, Univ. Thessaloniki, 19, 149.

Doorenbos J, Pruitt OW (1977) Crop water requirements. FAO *Irrigation & Drainage* Paper 24. Land and Water Development Division, FAO, Rome

Moundrakis, D.(1985): *Geology of Greece*, University Studio Press,Thessaloniki, p. 207. (In Greek)

Papadimos, D.K. Katsavouni, S.,(2007): Assessment of Ecosystem Water Needs for Water Resources Management at Catchment Level: The Case of Cheimaditida Lake – Greece *Water demand management in the Mediterranean, progress and policies*, Zaragoza, Spain

Soulios, G., (1986). *Hydrogeology* , Vol. I. University Studio, Thessaloniki, p. 295 (In Greek)

Thomthwaite, C, (1951): An approach toward a rational classification of climate, *Geogr. Rev.*, Vol. 38, pp. 55 – 94

Thomthwaite, C. Mather, J., (1955): The water Balance, *Climatology*, vol. VIII, No 1, New Jersey, pp. 1 -37.