*SSRG International Journal of Agriculture & Environmental Science (SSRG-IJAES) – Volume 6 Issue 6 – Nov - Dec 2019*

# Water Balance Parameters Estimation through Semi-Distributed, Rainfall-Runoff and Numerical Models. Case Study: Atalanti Watershed (Central – Eastern Greece)

Lappas Ioannis

*Dr. Hydrogeologist, General Secretariat of Natural Environment and Water, Department of Protection and Management of Water Environment, Division of Surface and Ground Waters*

*Amaliados 17 Str., Ambelokipi-Athens, P.C. 11523, Greece*

## *Abstract*

*There are a lot of hydrological models which simulate the water balance components including direct and basic flow also taking into account many hydro-meteorological data. The purpose of this study was the modelling of water surplus, surface runoff and infiltration into saturated and unsaturated zone, through different methods, providing reliable conclusions. In this research, three distinct models, namely, CLASS U3M-1D (semi-distributed), Rainfall-Runoff and MIKE SHE (numerical) model were employed to simulate the hydrological balance in the area of Atalanti watershed. The rainfall data from five meteorological stations covering the whole catchment area were selected and used (Atalanti, Aliartos, Pavlos, Theologos and Makrykapa). The use of daily data combined with geological and soil data as well as data from plant and vegetation leaf area, were an important tool for calibration and simulation of all physical processes. The balance was conducted for each soil material and evaporative, drainage and fluxes were simulated over time. The simulation period was determined for twenty years (1981-2001). Initially, digitalized maps were introduced to the models applied using a GIS environment. Overall, all the models were able to satisfactorily simulate the balance's parameters, representing all the hydrological data adequately. The results of this study were presented in a graphical form of the spatio-temporal variation which could be used for the optimal management of water resources as well as for the proper use of groundwater abstraction. Moreover, the modeling could become a tool for an optimal groundwater management approach. Finally, all the applied models were cross-compared taking also into account the results obtained from the classical water balance parameters' estimation methodologies.*

**Keywords —** *water surplus; model simulation; CLASS U3M-1D; Rainfall – Runoff model; MIKE SHE; methods' cross-comparison.*

## I. INTRODUCTION

The hydrometeorological-climatic characteristics of an area are the key factors of the hydrological cycle and consequently of its hydrological balance. Therefore it is necessary to study and analyze the spatial distribution of each climatic factor separately, as well as to investigate their interrelationships. The knowledge of the water balance parameters contributes to the rational design and operation of the various hydraulic and technical projects, the determination of the risk and susceptibility to floods and landslides as well as the quantification of the aquifers' natural recharge. Of the various types of precipitations (rainfall, snowfall, haze, etc.), there is particular interest in rainfall as it is quantitatively superior, while contributing to the replenishment of the aquifers. The geographical variability of rain and temperature is influenced by several factors, many of which are related to the nature of the evolution of the atmospheric systems that produce them. However, at the over-annual scale, the effects of at least two factors are evident: the proximity to the sea and the oreography, which contributes to the increase in rainfall and the decrease in temperature with increasing altitude [5]. The plotting of the oreographic relationship, that is, the curve of the change in rainfall height and temperature with altitude, is characteristic for each area under consideration and can vary considerably within the area as well.

The hydrometeorological data used in the present study come from five stations which all of them are related to rainfall, temperature, relative humidity and sunshine data. These stations are under the responsibility of the former Ministry of Environment, Physical Planning and Public Works (now Ministry of Environment & Energy) followed by the stations of the Hellenic National Meteorological Service (HNMS) and the Ministry of Agriculture Development and Foods. In order to obtain a picture of the spatial and temporal heterogeneity of the meteorological parameters in the wider study area, the data were processed on a monthly, seasonal and over-annual scale. Subsequently, the uniformity of the rainfall/temperature data was checked, the missing values of the above stations were supplemented by others closest to similar physiological characteristics and the relationship between the height of precipitation (rain gradient) and temperature (temperature gradient) was examined. At the same time, a number of basic statistical parameters were used, such as mean, maximum and minimum values, range, median, standard deviation, and the coefficients of kyrtosis and asymmetry, while a statistical distribution of the hydrometeorological variables was performed.

## II. MATERIALS AND METHODS

### *A. Study Area Location and Terrain Morphology*

The study area (Atalanti catchment) is located at Eastern Central Greece at Lokrida province of Fthiotida Prefecture and lies between $21^{0}44'$-$24^{0}39$ longitudes and $37^{0}45$-$39^{0}29'$ latitudes covering an area of 248km$^{2}$ (Fig. 1). The basin's altitude ranges between sea level and 1073 m (a.s.l.) with mean elevation of 275.3 m (a.s.l.) and elevation 50% of 210 m having also a diverged drainage (streams, rivers) with several kilometers of length which discharges into the sea. The study's area key feature is the flat surface formed somewhat above the sea level. The elevation variation between the lowest (sea level) and the highest point is approximately 663m (South of the city of Atalanti, mount Roda). The study area is open to the sea at Northeast and is surrounded by higher or lower mountains and hilly areas [11]. The combined effect of water's erosive ability and weathering processes as well as the geological and tectonic features are the key factors forming the current geomorphological conditions including both areas with mild slopes across the alluvial deposits and those with almost vertical slopes where the rocky cliffs prevail (carbonate rocks, ophiolites etc.). The drainage basin has flat relief mainly consisted of lowlands with gentle slopes up to $20^{0}$ and steeper ones in highlands with slopes reaching $55^{0}$ (approximately 3%). The drainage network in the valley is relatively dense due to semi-permeable formations while in the mountainous areas the active tectonics forms a sparse network with 1st or 2nd order streams, by Strahler, with steep slopes and deep river bed. The study area is surrounded by hilly and mountainous ranges accounting only for 2.2% (>800m) at the West and South (Mt. Chlomo) and washed by the sea at the East consisting a complex geomorphology. The semi-mountainous topographical zone accounts for 4.5% (600-800m) while the flat areas account for 39.5% (0-200m) mostly concerning the coastal areas. Also, the hilly and semi-hilly areas occupy almost 54% (200-600m) of the basin.

Moreover, the basin's elevation starts from the sea level ending up to 1073m above sea level (a.s.l.) crossed by a well-developed, partially densed and diverged dendritic drainage network which discharges into Aegean Sea. At the coastal region the flat and hilly relief prevails covering 76% of the basin area while the mountainous areas occupy only 24%. Also, only temporal streams exist, such as Alarginos and Karagkiozis (4th order by Strahler) flowing mostly during winter and spring after heavy rainfall events and forming as well V-shape rejuvenated valleys due to intensive tectonic activity. Within the mountainous ranges the first (1st) and second (2nd) order streams form steep slopes with deep river bed, in particular when carbonate geological formations prevail. Generally speaking, the drainage network within the lowlands is considered as dense due to semi-permeable formations (e.g., clays, silt, fine sand, marls) while in the rocky areas the intensive and active tectonics has formed a significantly sparse drainage ([8], [11], [12]). Finally, the regional area is characterized by mild wet winters and hot, dry summers (typical Mediterranean climate with $C_{sa}$ type according to Köppen classification) with the mean annual precipitation and the air temperature equals to 819.1 mm and $16.8^{0}$C respectively [8]. Almost 75% of the total rainfall takes place in the wet season from October to April with significantly rainfall non-uniformity between the lowlands and highlands.

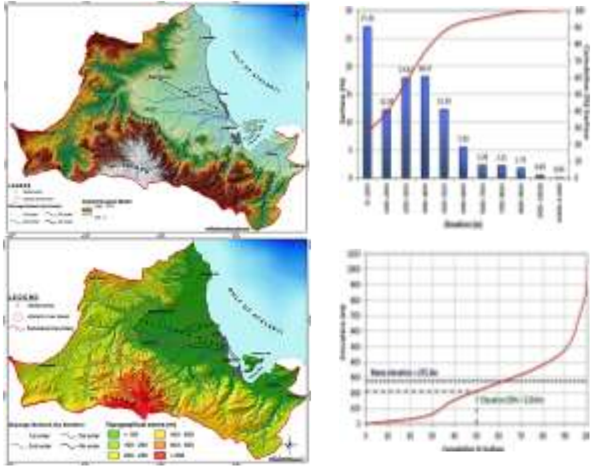


**Fig 1:** The study area's location with the main geomorphological features (topographical zones, hypsometric curve) and contributing drainage network.

### *B. Input Data*

The geo-referenced in GGRS 87 coordinating system topographic maps of 20m (scale 1:50,000) were obtained from the Hellenic Military Geographical Service (HMGS) where the drainage network of the Atalanti watershed is also delineated. According to the aforementioned maps the DEM of 25m grid cell resolution was derived and several calculations were also determined such as the slope, the aspect, the topographic zones, etc. Moreover, the geological and soil maps from the regional area of interest (scale 1:50,000) were obtained from the Hellenic Survey of Geology and Mineral Exploration (HSGME) and the Agricultural University of Athens to soil characterize the formations. Furthermore, daily, monthly and annual rainfall and temperature dataset for a large time period (1981-2010) from 5 meteorological gauge stations covering the regional area were obtained from the Hellenic National Meteorological Service (HNMS), the Ministry of Environment and Energy and the Ministry of Agriculture Development and Foods. Also, through CORINE Land Cover (2012), the study area's land use was identified and classified according to landslide susceptibility. All the aforementioned base and derived thematic spatial maps were pre-processed, analyzed and integrated together in a raster GIS environment transformed into a grid spatial database to display spatial information.

### C. *Methodology Analysis*

Water Balance Parameters Estimation through CLASS U3M – 1D and Rainfall – Runoff Modelling

In order to simulate the Atalanti watershed hydrological balance parameters the modeling of the balance parameters was applied with both semi-distributed models (CLASS – Catchment Scale Multiple – Landuse Atmosphere Soil Water and Solute Transport Model) and Rainfall – Runoff models. This is done in order to evaluate the water balance components through analytical – mathematical procedure and make a cross-comparison to check the results.

Richards/van Genuchten Equations of the Unsaturated Zone

The descriptions of the non-uniform unsaturated flow are based on Richards' equation [13], which combines the Darcy-Buckingham equation for the fluid flow potential with a mass balance equation [1]. The Richards' equation [10] typically predicts uniform flow processes in the unsaturated zone, although it is often transformed with spatial variables to describe changes in the soils' hydraulic properties (e.g., different soil layers). The unsaturated zone is extremely heterogeneous both at the level of microporous and at large areas. These inhomogeneities can lead to preferential flow processes, which are difficult to be described by the Richards' equation.

The groundwater flow in an unsaturated porous medium (soil) is usually described, in terms of mass balance, by the equation:

$$\frac{\partial \theta}{\partial t} = \frac{\partial q_i}{\partial x_i} - S$$

where,

$\theta$ the volumetric content of water [$L^3L^{-3}$], $t$ the time [T],

$x_i$ the spatial variable [L],

$q_i$ the volumetric flow density [$LT^{-1}$] and

$S$ a general source or loss term [$L^3L^{-3}T^{-1}$]. The above equation is often referred to as a continuity equation or mass conservation equation. This equation generally expresses the change in a given water volume due to spatial variations in flow potential.

The uniform flow is described by the Darcy-Buckingham equation as follows:

$$q_i = -K(h) \cdot \left( K_{ij}^{\mathrm{A}} \cdot \frac{\partial h}{\partial x_i} + K_{iz}^{\mathrm{A}} \right)$$

where,

$K$ the unsaturated hydraulic conductivity [$LT^{-1}$] and

$K_{i,j}{}^{A}$ the members of a two dimensional $K^{A}$ anisotropy panel (becomes uniquet when the medium is isotropic).

The Darcy-Buckingham equation is the same as the Darcy equation except that the ratio $K$ is a nonlinear function of the pressure profile (or water concentration), while in the Darcy equation $K(h)$ is constant and equal to $K_s$, which is the hydraulic conductivity of the saturated medium. Combining the mass conservation equation and the Darcy-Buckingham equation, we find:

$$\frac{\partial \theta(h)}{\partial t} = \frac{\partial}{\partial x_i} \left[ K(h) \cdot \left( K_{ij}^{\mathrm{A}} \cdot \frac{\partial h}{\partial x_j} + K_{iz}^{\mathrm{A}} \right) \right] - S(h)$$

This partial differential equation is the one that usually describes the non-uniform saturated flow in the unsaturated zone. It is quite non-linear and therefore is solved through the use of numerical solutions to practical problems using various numerical methods, such as finite differences or finite elements. The latter equation is often referred to in the literature as a mixed form of the Richards equation as it contains two dependent variables, the water content and the pressure profile.

Usually, the characteristic curve of soil moisture $\theta(h)$ is described by empirical functions, one of which is van Genuchten's. Van Genuchten [19] described the characteristic curve of soil moisture as follows:

$$S_e = \frac{a}{\alpha + h^b} \text{ , when } h>0$$

where,

$a$ and $b$ the adjustment parameters and $h$ the pressure load [L]. Van Genuchten defined the soil water content as follows:

$$\theta(h) = \theta_r + \frac{\theta_s + \theta_r}{\left(1 + \alpha \cdot h^n\right)^m}$$

where,

$\theta(h)$ the dimensionless soil water content, $\theta_r\theta_s$ is the residual soil moisture content and the soil water content saturation respectively [$L^3L^{-3}$] and

$a$, $n$, $m$ $(=1-1/n)$ numerical empirical parameters.

## III. RESULTS AND DISCUSSION

### A. *Application of a Semi-Distributed Model (CLASS U3M – 1D)*

It is about a groundwater flow and soil moisture distribution model in the unsaturated zone, based on the Richards (Unsaturated Moisture Movement Model) equation and is widely used to quantify hydrological balance components for any combination of climate conditions and land uses [18].

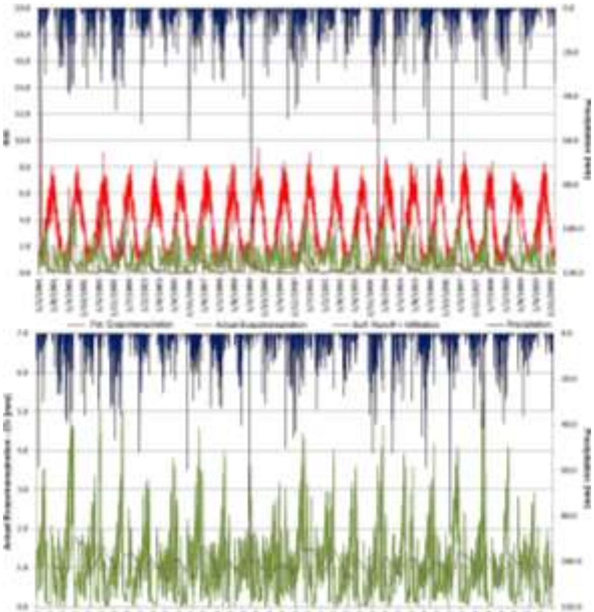


**Fig 2:** Daily variation of the water balance parameters in the Aliartos meteorological station (up) and daily variation of the actual evapotranspiration with the 1-year moving average (down).

This software accepts daily rain and potential evaporation values as input data. In this case, reliable daily maximum, minimum and mean precipitation values exist only from the Aliartos Meteorological Station, which is closer to the study area showing a very good correlation with the Atalanti rainfall Station ($R^2$=0.83) at both monthly precipitation and temperature. Potential evapotranspiration has been calculated based on the Hargreaves method, which is considered the simplest since it only uses temperature data, maximum, minimum and average values for a period of 21 years, from 01/01/1981 to 31/12/2001. Also, only one soil type is selected which is considered to be the most representative in the study area and in this case the selected soil type is sandy-clay-loam. Based on the above assumptions, the water balance of the entire Atalanti watershed is compiled, as shown in the graphs below (Fig. 2 – Fig. 4). It is therefore found that the average total amount of actual evaporation is 74.1% of the rain, with the remaining 25.9% corresponding to the sum of surface runoff and infiltration. These two percentages are very close to those obtained from the classical water balance estimation methodology.

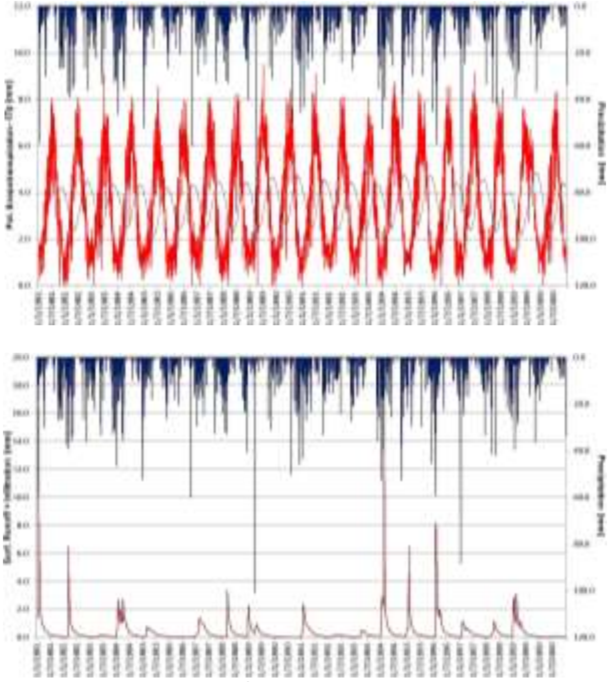


**Fig 3:** Daily variation of the potential evapotransiration with the yearly moving average (up) and daily variation of the sum of surface runoff and infiltration (down).

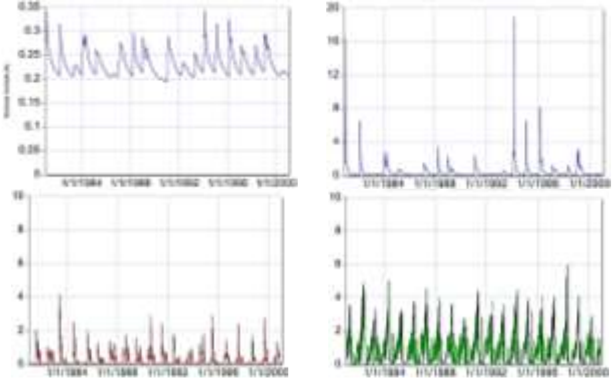


**Fig 4:** (a) Soil moisture variation (%) with time, (b) daily groundwater leakage from unsaturated to saturated zone with time, (c) plant transpiration variation with time and (d) water evaporation variation from woil with time.

### B. *Application of a Rainfall-Runoff Model*

Thornthwaite's simple Rainfall-Runoff model is based on the simulation of the catchment’s hydrological function with the operation of a simple reservoir. The reservoir represents the storage of soil moisture $S$, while the reservoir overflows when the reservoir exceeds the reservoir capacity $K$. The overflow represents the surface runoff, which only occurs when the reservoir is filled or the soil is saturated. Rainfall P and potential $ET_p$ evapotranpiration, as well as storage at the end of the preceding $S_{n-1}$ period, are already known for the model computational operation at any time period. Model outputs are actual $ET_r$ evapotranspiration, surface runoff $Q_n$, and infiltration I, as well as the storage at the end of the current $S_n$ period ([2], [4]). In times where precipitation is greater than potential evaporation $(P>ET_p)$, the actual evaporation equals to potential. The surplus $(P–ET_p)$ is stored as soil moisture if the soil is unsaturated. When saturated, the amount that can no longer be stored flows superficially. At times when the rainfall is less than the potential evaporation $(P<ET_p)$, the actual evaporation is less than the potential. In particular, it is assumed that at first all the amount of rainfall P is evaporated and in case where soil moisture is stored, an additional part of it is evaporated. The rate of extra evapotranspiration is proportional to the difference $(ET_p–P)$ as well as to the soil storage and in particular the $S/K$ ratio. The above function can be mathematically coded as follows:

a) If $P \geq ET_p$ then $S_n = \min(S_{n-1}+P-ET_p, K)$ and $Q_n = \max(S_{n-1}+P-ET_p-K, 0)$

b) If $P<ET_p$ then $S_n = S_{n-1}\exp[(P-ET_p)/K]$ and $Q_n=0$

In any case, the actual evapotranspiration is resulted directly from the equation $ET_r=(S_{n-1}-S_n)+P-Q_n$. In conclusion, the simple Thornthwaite model uses the rainfall and the potential evapotranspiration as input data and while the actual evapotranspiration as output, using only one parameter the capacity of the $K$ reservoir (the value used here is R=130mm). Below, in Table 1, the parameters of surface runoff and infiltration are quantitatively estimated taking into account all stations of the regional area with rain and temperature data using the Thornthwaite method for the calculation of potential evapotranspiration. Then the results are compared with those derived from classical methods. This model operates on a monthly basis and is suitable for watersheds, which fulfill certain conditions, such as (a) no surface runoff during summer (b) small areal extent with relative uniformity both in terms of topography and geology as well as hydroclimatic conditions, (c) basins without important water projects affecting the hydrological diet and (d) no significant groundwater leakage from or to adjacent basins. By comparing (Fig. 5) the classical methodology, according to Thornthwaite-Mather [17] with that of Thornthwaite's Rainfall-Runoff model [16], it appears that the values of both actual evapotranspiration and water surplus are almost identical.

**TABLE I**

**Water balance parameters calculation (mm) according to Rainfall-Runoff model (by Thornthwaite). The values within brackets represent the % percent.**

| **Stations** | **Precip.** | **Act. Evapotr/tion** | **Water Surplus (Sur. Runoff+Infiltr.)** |
|---|---|---|---|
| Aliartos | 594.4 | 408.9 *(68.8)* | 185.5 *(31.2)* |
| Pavlos | 571.8 | 447.5 *(78.3)* | 124.3 *(21.7)* |
| Atalanti | 554.7 | 429.1 *(77.4)* | 125.6 *(22.6)* |
| Theologos | 671.1 | 492.0 *(73.3)* | 179.1 *(26.7)* |
| Makrykapa | 1038.5 | 498.4 *(48.0)* | 540.1 *(52.0)* |

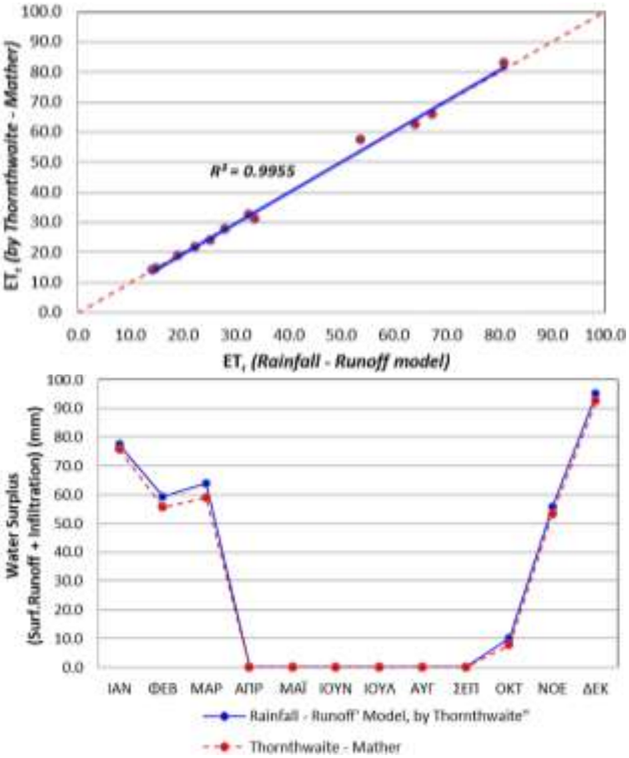


**Fig 5:** Correlation between the actual evapotranspiration ETr, by Thornthwaite – Mather based on Rainfall – Runoff model (left) and comparison of the monthly water surplus between the two methods during the period 1981-2001.

### C. Application Field of Hydrological Modelling of a Rainfall-Runoff Model

For the representation of the catchment's natural processes mathematical models have been developed which, using data from the field measurements' processing and a set of assumptions about the mathematical representation of the catchment processes, estimate its diet on various spatial and temporal scales [7]. These models contribute to an understanding of the mechanisms associated with the water cycle and are also used as models to predict the evolution of the hydrological basin, provided the baseline conditions and input data are already known. Hydrological models are divided into different categories according to their (a) scope, (b) mathematical structure and (c) temporal discretion. As a rule, the application field of hydrological models is either the catchment area or the aquifer. The development of separate models for each field is required due to their different management practices, but also due to the different spatial evolution scale of the relevant physical processes. The case of combined simulation of surface and groundwater processes is considered necessary when water uses and a significant contribution of groundwater potential to the overall basin runoff are combined. The combined simulation necessarily requires a less detailed description of the physical system; however, it provides a more complete and therefore more realistic picture of the hydrological processes [20].

Mathematical Structure – Time Discretion – Calibration

Hydrological models depending on their mathematical structure fall into two categories [14]: the first are conceptual models, which represent the main hydrological processes of either the entire basin or its sub-basins, considering a predetermined mathematical structure based on empirical assumptions, for the most part. The advantage of these models is their simplicity, which allows for the representation of complex physical processes, characterized by strong spatial heterogeneity, through a relatively small number of parameters. Depending on the spatial resolution and how their parameters are determined, conceptual hydrological models are divided into: (a) Undivided, in which the main hydrological processes are represented, in order to estimate the outflow to this outlet, (b) Semi-distributed, in which the watershed is divided into discrete units, corresponding either to natural sub-basins or to areas with common hydrological and geomorphological characteristics, each of which corresponds to different input data and different parameter values and (c) Semi-undivided, in which basins are considered distinct sections, each of which receives a different charge, but the parameters are commonly applied to all sections. The second category includes distributed based models, which represent small-scale hydrological processes, based on natural laws, related to the water flow, as well as semi-empirical relationships that have emerged from research conducted in experimental basins. Because the discretization is dense, the model's characteristic sizes are extremely large and are estimated solely in relation to the basin's physical characteristics (topographic, soil, geological, hydrogeological, etc.) as well as field measurements. In general, physical-based models are used for more specialized research, such as impact assessment, climate change, vegetation cover or land use in a basin often combined with pollution transport-diffusion or load-transfer models.

In terms of time discretion, this is directly dependent on the model’s purpose. Simulation schemes used for management purposes adopt the monthly or, more rarely, the daily scale, whereas the flood models use smaller scales [15]. The hydrological models’ parameters can be indirectly estimated through a systematic evaluation of alternative combinations, called calibration. The calibration is done by comparing the simulated responses of the basin (or aquifer) with those observed by selecting the combination that achieves the best fit. Calibration refers to a sufficient period of time for which systematic response measurements are available, so that historical data can be compared with simulated data. The procedure is followed by the so-called model validation, which tests its predictive ability for another (usually later) time period.

Physical Based Models

Physical based models began to be developed in the mid-1980s in order to address some of the weaknesses of conceptual models, most notably their inability to simulate ungauged basins, since their parameters are estimated exclusively by calibration. On the contrary, the parameters of the physical based models are known, as they are directly related to the characteristics of the natural system, which change not only spatially but also temporally due to land use changes.

### *D. Hydrological Flow Model (MIKE SHE)*

General Description

MIKE SHE (Système Hydrologique Européenne) is a powerful integrated hydrological cycle simulation tool. The model has an extremely wide range of applications to surface and groundwater resources as well as to environmental problems such as: (a) water basins’ design and management, (b) water supply design, management and optimization, (c) soil irrigation and drainage, (d) soil and water management, (e) impact on surface water from groundwater abstraction, (f) combined ground and surface water management, (g) management and wetland restoration; (h) environmental considerations and assumptions, (i) groundwater management, (j) environmental impact assessment; (k) mapping the aquifer’s vulnerability; (l) contamination from waste disposal, (m) surface and groundwater quality restoration, (n) flood studies, (o) impact of land use and climate change and (p) impact of agriculture (irrigation, drainage, pesticides, ingredients, etc). The model represents the following processes, such as precipitation (rainfall, snowfall) evapotranspiration including flora obstruction, groundwater runoff, streamflow/open channels, unsaturated and saturated groundwater flow. For each process, MIKE SHE provides alternative mathematical description modules, ranging from simple to sophisticated, distributed-based physical approaches. Hydrological data may be fixed values or time series, referring either to space dots or to matrix cells. The model’s shape and the solution of the static equations are considered at a cell level, which allows the model to function as a fully spatially distributed one.

MIKE SHE is a flexible model whose framework includes numerical methods for each hydrological process including tools for both pre-processing and post-processing. Hydrological methods can be combined at different levels of spatial distribution and complexity, which depends on application requirements and data availability. MIKE SHE is a physically based, deterministic and fully spatially distributed model, since the equations are solved at cell scale. To simulate the water balance of the Atalanti watershed, a semi-distributed model is used, in which the shallow runoff as well as the basic runoff are simulated as a system of linear reservoirs. This is because it is practically impossible to simulate the aquifers on such a large extent in terms of finite difference, mainly because the knowledge of the aquifers' characteristics is extremely incomplete and the computational power as well as time requirements will be enormous. The unsaturated flow model is a soil profile model, which interacts with both the surface flow and the groundwater model (since the aquifer's water level is the lower boundary condition of the unsaturated zone).

MIKE SHE provides three different approaches: (a) a simple water balance model, which assumes discretization of two zones, (b) a gravity flow model and (c) a complete Richards' equation model. The unsaturated flow model cooperates with the evapotranspiration model, which is estimated based on the potential evapotranspiration, the available soil moisture and the flora characteristics, while the MIKE SHE groundwater flow model includes a two-dimensional and a three-dimensional model of finite differences. In physically based models, such as MIKE SHE, most parameters have a natural meaning and can theoretically be measured in the field, that is, there is a range of values within which each parameter receives certain values. The model calibration involves the parameters' selection, which each one plays a key role in the natural process of converting rainfall into runoff. The success of the hydrological model implementation and its accurate adjustment depends on the reliable input data. Rainfall and meteorological data from the adjacent stations have been selected and the use of daily data, in combination with geological and soil ones are an important background for the proper calibration and simulation of all natural processes. MIKE SHE, therefore, offers integrated modeling of groundwater, surface water, recharge and evapotranspiration.

Model Parameters' Specification – Parameterization

In a semi-distributed hydrological model the parameters do not always have natural meaning and the parameterization is an optimization process, not necessarily subject to physical boundaries. However, a fully physically distributed hydrological model by definition only contains parameters that could be estimated from field measurements. This implies that adjustment in case of insufficient data is not necessary, but also the inability to find all spatial and temporal variables and the input model parameters require to be calibrated. The purpose of adjusting a physical model is to find the best natural, realistic parameters that can simulate the behaviour of a watershed as accurately as possible. In the case of the MIKE SHE hydrological model the data can be static or dynamic as well as spatial or non-spatial (or a combination of both). Once the type of simulation is selected, the key elements introduced into the hydrological model are the followings:

Simulation Grid: the geographical area is defined including the simulated area's boundaries. The simulation grid can include only one catchment area or a larger one, which includes more basins. All simulation processes are done within square cells of similar dimension, fully covering the simulation grid. The size of each cell can vary and usually ranges from about 200m for detailed limited area simulations and can reach up to 5000m or more if extensive catchments are simulated. The size of the grid affects the simulation speed and is an optimal compromise between the accuracy of the simulated area and the available spatial data [21].

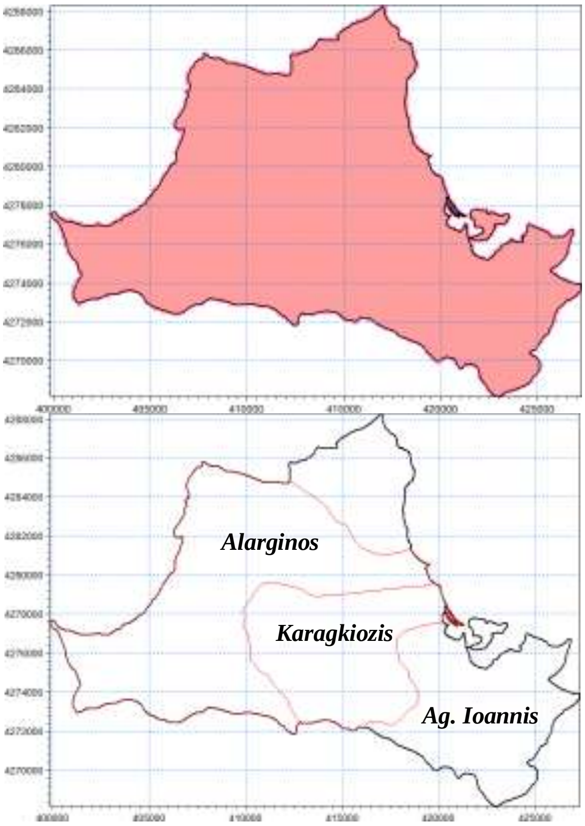


**Fig 6:** Simulation grid with the main sub-basins (Alarginos, Karagkiozis, Ag. Ioannis).

Sub-watersheds: the individual basins are defined (Fig. 6). In the case that the simulation grid contains more sub-basins, a polygon file is inserted specifying the individual sub-basins of the simulation grid. In this case, the applied model treats each basin separately and calculates the water balance components for each of them separately, while remaining able to derive results for the entire simulation grid. In the present paper, three major sub-watersheds (Alarginos, Karagkiozis and Ag. Ioannis) have been used for hydrological simulation, while the other ones are of secondary importance and are also used to estimate the hydrological balance components for the entire basin.

Terrain: the digital elevation model (DEM) of the simulation grid is given which describes the altitude and terrain of the study area. DEM is used to route the direct runoff, as well as to determine the aquifer's depth when a detailed simulation is carried out (Fig. 7).

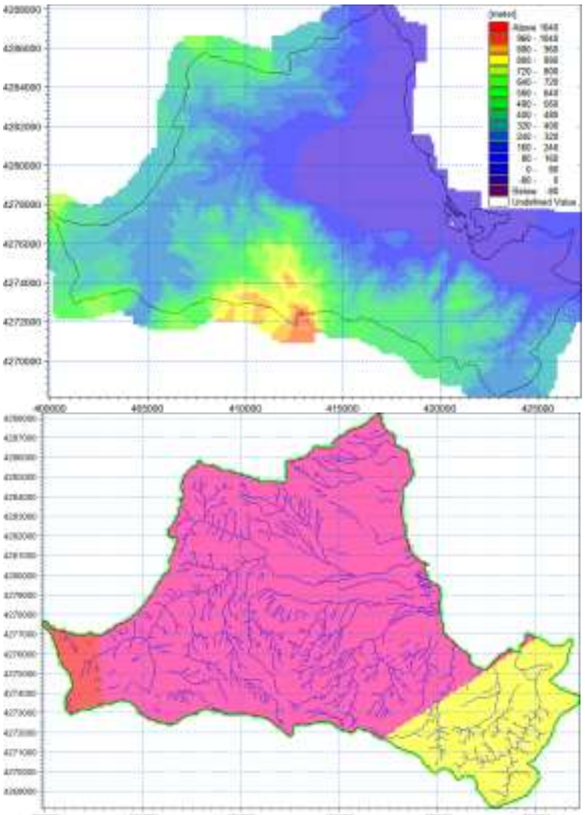


**Fig 7:** Digital elevation model (left) and Thiessen polygons with the rain stations of the study area (Atalanti-pink, Elatia-red, Pavlos-yellow) (right).

Hydrometeorological data: daily time series data on rainfall, temperature and potential evapotranspiration are given. In the present study, the rain parameter was introduced based on Thiessen polygons of the adjacent stations (Atalanti, Elatia and Pavlos) in the form of a polygon file. For each polygon Thiessen the rainfall time series is given, while daily temperature and potential evapotranspiration values are given on a station basis (Aliartos) also considered the same for the entire basin (Fig. 7).

Actual Evapotranspiration: is calculated by the model based on the Kristensen-Jensen method, after the estimated potential evapotranspiration has been introduced into the software based on the Hargreaves equation (Fig. 8). This method distinguishes the processes which relate to actual evapotranspiration in four categories: (a) the partial rainfall retention from the vegetation, (b) the part of the rain that reaches the ground either flowing on the surface or infiltrating into the unsaturated zone, (c) part of the infiltrated water either evaporated from the upper soil layer or used by the vegetation and (d) the rest recharges the aquifers. The amount of plant respiration depends on the LAI, the rooting depth (RD) and the soil moisture available throughout the root system. The soil moisture evaporation from the upper layer of the unsaturated zone obviously depends on the available soil moisture.

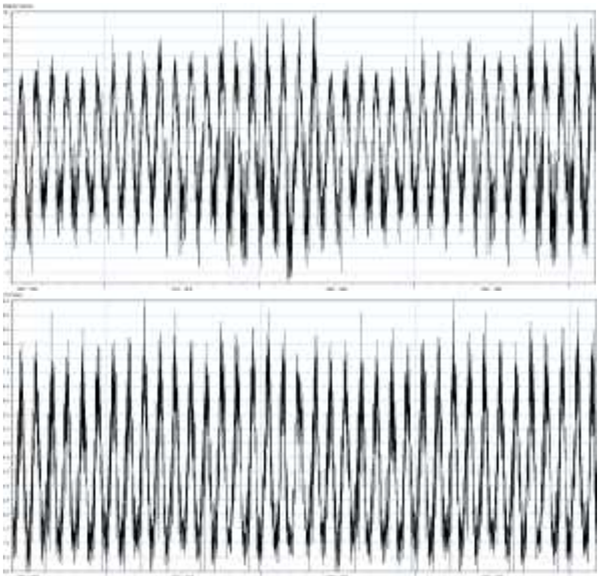


**Fig 8:** Daily temperature data (in $^{0}$C) (up) and potential evapotranspiration (in mm/day) (down) of Aliartos meteorological station, derived by MIKE SHE model for the water balance parameters estimation (simulated period 1964 – 2010).

Land Use and Vegetation Cover: the simulated land use and vegetation cover through the CORINE Land Cover, 2000 is given. The data is entered in the form of a polygon file, each corresponding to a different land use/vegetation cover characterized by the corresponding CORINE code. Also, the Leaf Area Index – LAI and Rooting Depth are introduced for each vegetation category. When the land use described by the CORINE database relates to urban, commercial or industrial uses (e.g., continuous urban construction, port or airport zones, industrial zones, etc.) these indicators are set equal to or nearly equal to zero.

Direct Surface Runoff: fixed parameters are defined on the basis of which the model calculates the direct runoff component, that is, that portion of runoff, which flows directly without infiltrating into the subsoil. Its spatial variation can be defined either uniformly over the whole simulation grid or distributed by a spatial variable. In this case the study area is divided by topographic zones, i.e., 0-100m lowland area, 100-200m semi-plain area, 200-400m semi-hilly area, 400-600m hilly area, 600-800m semi-mountainous area and >800m mountainous area. For each of these, the slope (%), the Manning number (n) and the detention storage in mm were estimated (Fig. 9).

Flow in the Unsaturated Zone: the characteristics of the soil layers, covering the simulated grid, are specified. A simplified two-layer model is used to simulate the flow in the unsaturated zone. The upper layer consists of the root system in which the available soil moisture is the limiting factor for calculating the actual evapotranspiration as part of the potential. The lower layer is below the root system, but above the aquifer. Four parameters are specified for each soil type: (a) the saturation rate (soil water content at saturated conditions), (b) the soil water content at field capacity, (c) the soil water content at field wilting point and (d) the infiltration rate (K in m/sec). The difference in water capacity is extremely important as it shows the amount of water that can hold any type of soil available for evaporation. The volume of surface runoff depends significantly on the value of the hydraulic conductivity. The soil map (Fig. 10) of the study area was produced with the contribution of both Forest Institute at a scale of 1:50,000 and the geological background ([3], [6], [9]).

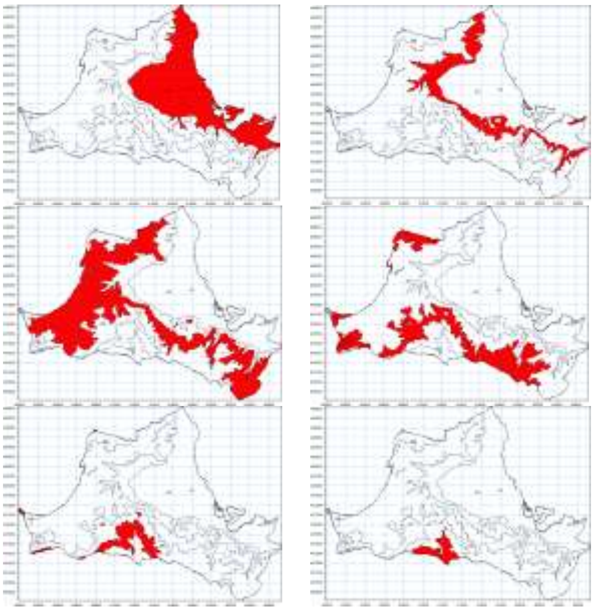


**Fig 9:** The direct surface runoff based on topographical zones (0-100m, 100-200m, 200-400m, 400-600m, 600-800m and >800m).

Flow in the Saturated Zone – Interflow: this flow type typically corresponds to relatively high intensity storms when the rainfall rate is such that exceeds the basin's absorption rate. The interflow is simulated with a system of dual outlet linear reservoirs, one lateral showing rapid surface runoff and one at the bottom, showing the infiltration in the linear basin reservoirs (Fig. 11).

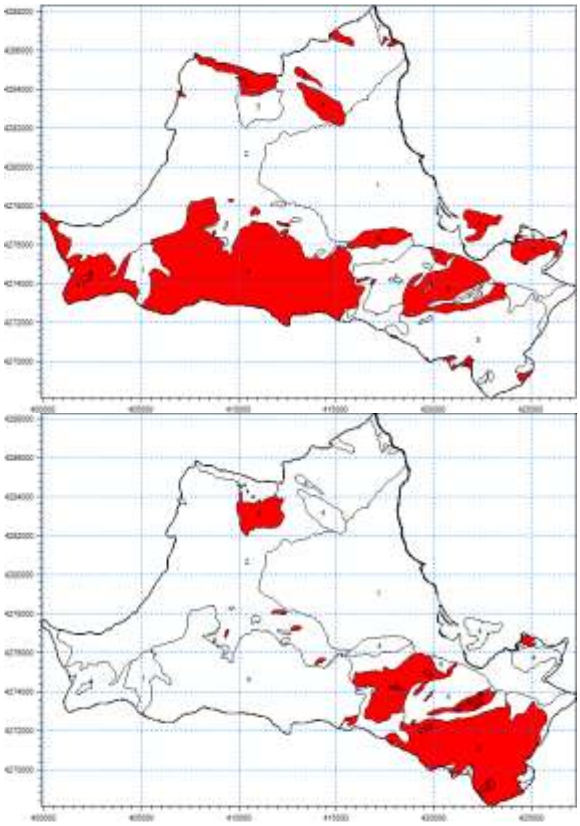


**Fig 10:** Spatial distribution of the different soil formations (alluvial soils, silt-clay soils, clay soils and clay-silt acid soils).

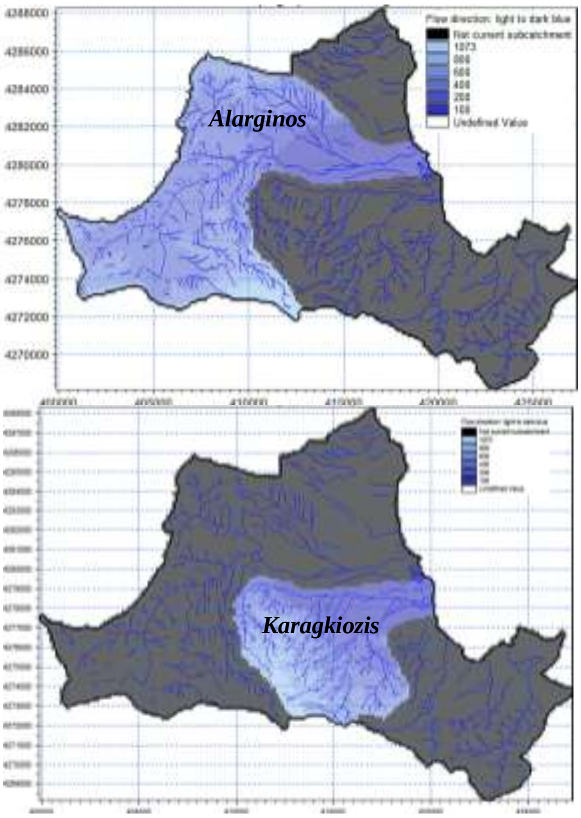
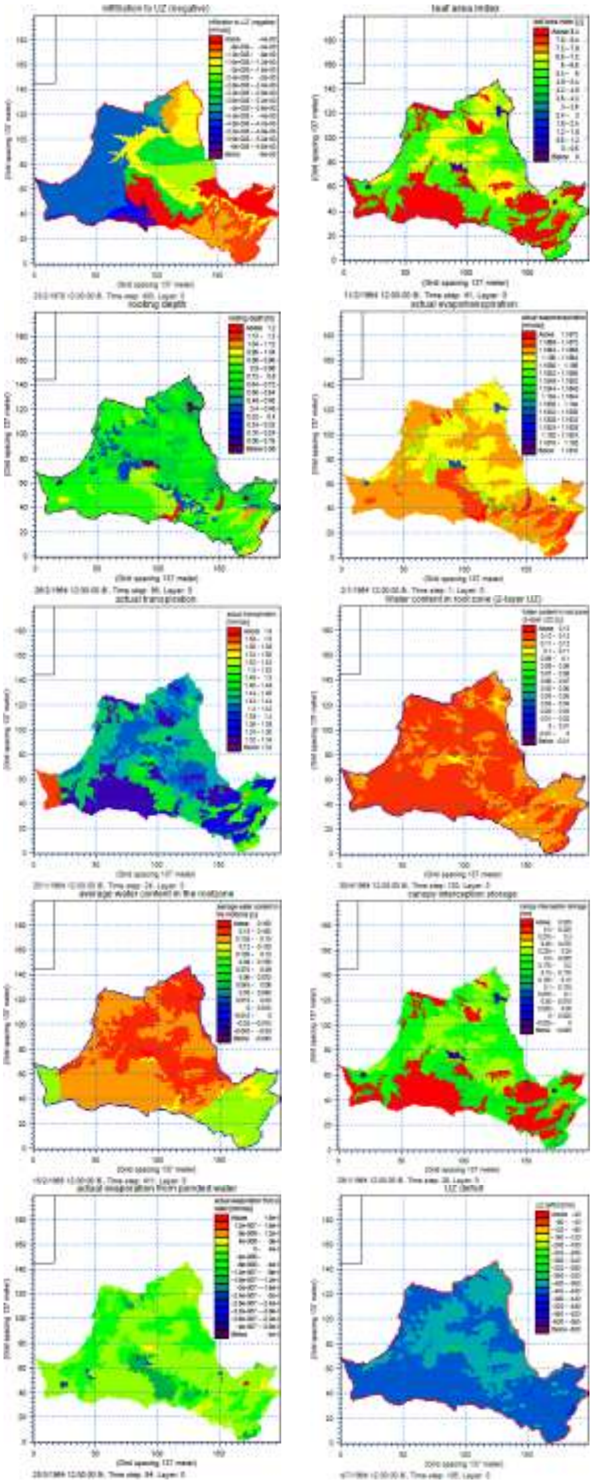


**Fig 11:** Flow direction and direct surface runoff routing to the main streams, Alarginos and Karagkiozis.

### *E. MIKE SHE Model Application in the Study Area*

The success of the hydrological model implementation and its subsequent adjustment depends on the input data, which means that the more representative ones, the more accurate the model will be. In addition, the water balances, which have been obtained for the entire watershed and the individual sub-basins from the model performance, are presented.



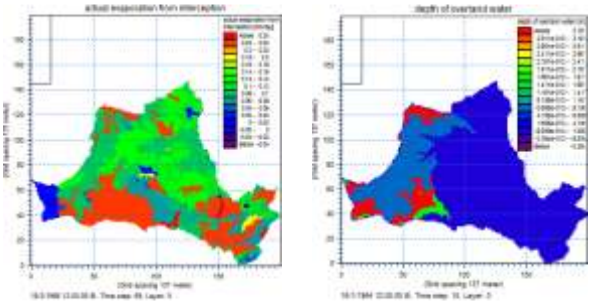


**Fig 12:** Indicative results of the Atalanti catchment’s hydrological characteristics based on the MIKE SHE model.

The hydrological years from 1964 to 2010 in order to calibrate the hydrological model were defined, since precipitation, temperature and evapotranspiration measurements on a daily basis exist. The efficacy of the model and the interventions in its adjustment and ultimately the accuracy of its results can be evaluated by both graphically and statistically methods, while the model results are then compared with those derived from both Rainfall-Runoff model, by Thornthwaite, and the semi-distributed one (CLASS U3M-1D) as described before.

The simulation selected for the study area is sub-catchment based, with two layers for the unsaturated zone. The simulation grid includes the catchment area, with the possibility to include more than one sub-basin. All processes are done through square cells of similar size, which fully cover the simulation basin. Representative (actual) values were taken into account in the procedure execution where data from previous surveys and studies were already available. The topography determines the upper bound of the groundwater flow model as well as the upper bound of the unsaturated zone. The digital terrain model was used to route the direct runoff as well as to determine the aquifer’s depth. The study area could also be simulated using a single basin, but its separation is useful for drawing individual conclusions about the sub-catchments of Alarginos, Karagkiozis and Ag. Ioannis.

The parameters for each land use to be included in the model are the rooting depth, the Leaf Area Index and the vegetation coefficient-$K_c$. Land uses are mainly related to forests, shrubs, natural pastures, alluvial deposits and areas of agricultural land with vegetation. The maximum detention storage parameter, that is, the maximum height of water that can be retained on the soil surface prior to direct runoff, affects the calculation of actual evapotranspiration and ranges from zero to very small and up to a few millimeters for the lowlands areas (0.0-0.3mm). The lack of soil maps is an obstacle to the hydrological simulation, as there is insufficient soil texture data (e.g., percent of sand, silt and clay content) which would greatly help in determining the moisture values in the water potential capacity, the withering limit and the infiltration capacity. The processing of rainfall and other meteorological data is the most important process of model application as precipitation is the main parameter influencing both the evapotranspiration and surface runoff.

Data Pre-processing: the model's required data must be pre-processed. This process extracts all spatial data adapting them to the specified numerical model. Below, in Table 2, the hydrological balance components are separately depicted for each catchment. The table below shows a relative uniformity of the hydrological balance parameters with the results obtained from both the classical methods and the implementation of specialized software for water balance simulation which leads to the conclusion that the simulation results with MIKE SHE model are satisfactorily performed, reliably approaching the physical processes (Fig. 12 – Fig. 13).

**TABLE III**

**Water balance parameters' estimation (in mm) for the study area's sub-basins.**

| **Sub-basin** | **Area ($\times 10^6 m^2$)** | **Mean Precipitation** | **Mean Evapotr/tion** |
|---|---|---|---|
| Alarginos | 109.1 | 565.5 | 391.6 |
| Karagkiozis | 55.2 | 565.7 | 391.4 |
| Ag. Ioannis | 55.4 | 562.3 | 389.7 |
| Rest | 29.8 | 535.3 | 374.8 |
| ***SUM*** | ***249.5*** | ***551.9*** | ***458.0*** |
| **Sub-basin** | **Mean Sur.Runoff** | **Mean Infiltration** | **ΔS (Storage)** |
| Alarginos | 37.7 | 138.5 | -2.3 |
| Karagkiozis | 34.2 | 142.4 | -2.3 |
| Ag. Ioannis | 34.3 | 140.5 | -2.2 |
| Rest | 28.6 | 134.1 | -2.2 |
| ***SUM*** | ***24.4*** | ***74.2*** | ***-4.7*** |

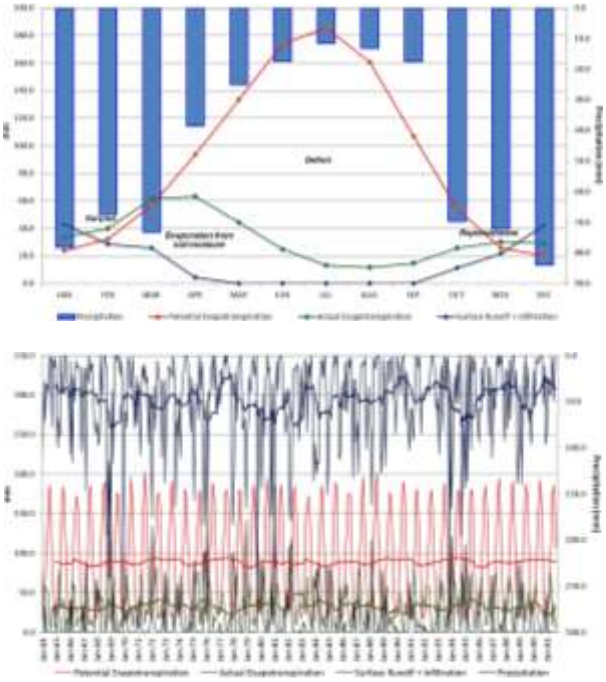


**Fig 13:** Mean monthly water balance parameters variation for the Atalanti watershed (up) and the parameters' monthly distribution with the 1-year moving average (down).

## IV. CONCLUSIONS

In the present essay described above, the water balance parameters were estimated through different methods using either simple equations or more complex ones. All kind of available data were gathered, that is, the daily meteorological data from adjacent meteo stations as well as the geological and soil data and introduced into the models so as to simulate the hydrological and physical processes occurred in Atalanti watershed. All the models' results were cross-compared showing that there is no much difference between them. Moreover, the results obtained from the three models showed no significant difference when compared to classic methodologies. The data were pre-processed in a GIS environment during the time period from 1981 to 2001 and then introduced into the models to be simulated. As a result, the models require reliable and accurate data and if correctly pre- and post-processed the conclusions can be proved very important as far as the sustainable surface and groundwater management is concerned. Finally, it has to be mentioned that the classic water balance estimation methods can also give the appropriate directions to rational use of surface and groundwater resources if validated by more sophisticated models with, more or less, complex mathematical equations.

## ACKNOWLEDGMENTS

The author wish to express his thanks to the Hellenic Military Geographical Service (HMGS) for the topographical maps obtained as well as the Hellenic National Meteorological Service (HNMS), the Ministry of Environment and Energy as well as the Ministry of Agriculture Development and Foods for the meteorological stations' precipitation and temperature dataset of the regional area. Also, many thanks to the Hellenic Survey of Geology and Mineral Exploration (HSGME) and the Agricultural University of Athens for the given geological and soil maps.

## CONFLICT OF INTERESTS

No potential conflict of interest was reported by the authors.

## REFERENCES

[1] H. Brooks, T. Corey. Properties of porous media affecting fluid flow. Journal of the Irrigation & Drainage Division, American Society of Civil Engineers, pp.61-88, 1966.

[2] A. Efstratiadis, I. Nalbantis, A. Koukouvinos, E. Rozos, D. Koutsoyiannis. HYDROGEIOS: a semi-distributed GIS-based hydrological model for modified river basins. Hydrology and Earth System Sciences, 12, pp.989–1006, 2008.

[3] D. Katakouzinos. Soil map of Greece, scale 1:1,000,000. Ministry of Agriculture, Institute of Fertilizers and Climatology, Athens 1967.

[4] D. Koutsoyiannis. A generalized mathematical framework for stochastic simulation and forecast of hydrologic timeseries. Wat. Resour. Re. 36(6), pp.1519-1534, 2000.

[5] C. Kusre, S. Singh. Study of Spatial and Temporal Distribution of Rainfall in Nagaland (India). International Journal of Geomatics and Geosciences, Vol.2, No.3, 2012.

[6] G. Maratos, K. Rigopoulos, A. Athanasiou. Geological maps of Atalanti and Livanates sheets, scale 1:50,000, Institute of Subsurface Geological Research, 1965.

[7] N. Labrakis, G. Kallergis. Reaction of subsurface coastal aquifers to climate and land use changes in Greece. Modelling of groundwater refreshening patterns under natural recharge conditions. Journal of Hydrology, 245, pp.19-31, 2001.

[8] I. Lappas. Applied hydrogeological research in coastal aquifers. Case study of the coastal part of Atalanti region, Prefecture of Fthiotida. PhD Thesis Dissertation, School of Mining and Metallurgical Engineering, National and Technical University of Athens, p.487, 2018.

[9] G. Nakos. Soil map of Greece, scale 1:500,000. Institute of Forest Research, General Directorate of Forests and Environment, Athens 1977.

[10] Y. Pachepsky, D. Timlin, W. Rawls. Generalized Richards' equation to simulate water transport in unsaturated soils. Journal of Hydrology 272, pp.3–13, 2003.

[11] N. Palyvos. Geomorphological study of Atalanti area of Fthiotida prefecture. PhD Thesis Dissertation, School of Sciences, Department of Geology, Athens, 2001..

[12] D. Pantosti, P. DeMartini, D. Papanastassiou, N. Palyvos, F. Lemeille, G. D'Addezio, L. McNeill, K. Gaki-Papanastassiou, G. Stavrakakis. Geomorphological and paleoseismological studies of the Atalanti fault. XXVII Gen. Assembly of the Eur. Seism. Comiss., Lisbon Univ., Lisbon, p.73, 2000..

[13] A. Richards. Diagnosis and improvement of saline and alkali soils. Agric. Handbook 60, U.S. Dept. Agric, Washington, D.C. p.160, 1954..

[14] A. Romanowicz, M. Vanclooster, M. Rounsevell, I. La Junesse. Sensitivity of the SWAT model to the soil and land use data parameterization: a case study in the Thyle catchment, Belgium. Ecological Modelling 187, pp.27–39, 2005.

[15] D. Saleh, C. Kratzer, D. Green. Evans Using the Soil and Water Assessment Tool (SWAT) to Simulate Runoff in Mustang Creek Basin, California. Scientific Investigations Report 5031, 2009.

[16] W. Thornthwaite. An approach towards a rational classification of climate. Geogr. Rev. 38, pp.55- 94, 1951.

[17] W. Thornthwaite, R. Mather. The water balance. Thornthwaite Ass. Lab., New Jersey. Climatology 8 (1), pp.1-37, 1955.

[18] K. Tuteja, J. Vaze, B. Murphy, B. Beale. CLASS – Catchment scale multiple – landuse atmosphere soil water and solute transport model. Department of Infrastructure, Planning and Natural Resources and Cooperative Research Centre for Catchment Hydrology, Technical Report 04/12, Australia, 2004.

[19] M. van Genuchten. A Closed Form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils. Soil Sc. Soc. Am. J., 48, pp.892-898, 1980.

[20] E. Varanou, E. Gkouvatsou, E. Baltas, M. Mimikou. Quantity and quality integrated catchment modelling under climatic change with use of Soil and Water Assessment Tool model. Journal of Hydrologic Engineering 7, pp.228-244, 2002.

[21] F. Vazquez, L. Feyen, J. Feyen, C. Refsgaard. Effect of grid size on effective parameters and model performance of the MIKE SHE code. Hydrological Processes, 16, 2, 2002.