Using ArcSWAT to Predict Discharge in Ungauge Torrents of Thasos Island

Paschalis Koutalakis[1], George N. Zaimes[2], Dimitrios Emmanouloudis[3], Konstantinos Ioannou[4] and Valasia Iakovoglou[5]

[1]Labaratory of Management and Control of Mountainous Waters (Lab of MCMW), Department of Forestry and Natural Environment Management, Eastern Macedonia and Thrace Institute of Technology (EMaTTECH), 1st km Drama, Mikrohoriou, Drama, Greece 66100, e-mail: koutalakis_p@yahoo.gr
[2]Labaratory of Management and Control of Mountainous Waters (Lab of MCMW), Department of Forestry and Natural Environment Management, Eastern Macedonia and Thrace Institute of Technology (EMaTTECH), 1st km Drama, Mikrohoriou, Drama, Greece 66100, e-mail: zaimesgeorge@gmail.com
[3]Labaratory of Management and Control of Mountainous Waters (Lab of MCMW), Department of Forestry and Natural Environment Management, Eastern Macedonia and Thrace Institute of Technology (EMaTTECH), 1st km Drama, Mikrohoriou, Drama, Greece 66100, e-mail: demmano@teikav.edu.gr
[4]Labaratory of Management and Control of Mountainous Waters (Lab of MCMW), Department of Forestry and Natural Environment Management, Eastern Macedonia and Thrace Institute of Technology (EMaTTECH), 1st km Drama, Mikrohoriou, Drama, Greece 66100, e-mail: ioannou.konstantinos@gmail.com
[5]Labaratory of Management and Control of Mountainous Waters (Lab of MCMW), Department of Forestry and Natural Environment Management, Eastern Macedonia and Thrace Institute of Technology (EMaTTECH), 1st km Drama, Mikrohoriou, Drama, Greece 66100

Abstract. Water resources management requires the knowledge of the environmental conditions and hydrologic processes. The development of Geographic Information Systems (GIS) has allowed the use of spatially and physically based hydrologic models in order to simulate the hydrology in a complicated natural system. It is very important to use such tools especially in regions with limited available data. In this context, the objective of this study is to model the hydrologic conditions in the island of Thasos by using the Soil and Water Assessment Tool (SWAT) in a GIS environment. In order to understand the hydrologic processes, it was required to predict the water balance of the island and simulate the discharges of its ungauged torrents. The outputs of the model revealed the simulated values of the hydrologic phases, the torrent discharges and a map that identifies the watersheds with the highest discharges. The results could be used by experts and by every interested authority in order to manage the surface stream water for various purposes, such as suppression of forest fires.

Keywords: hydrologic modeling, water balance, GIS, water management

---

Proceedings of the 7th International Conference on Information and Communication Technologies in Agriculture, Food and Environment (HAICTA 2015), Kavala, Greece, 17-20 September, 2015.

1 Introduction

Surface water and especially stream and torrent flow is important for environmental scopes including the sustainability of living organisms and habitats in and adjacent to the stream and torrent but also for human purposes (Arthurton et al., 2007). The proper management can combine these two scopes, mitigate any possible negative influences on the environment but also utilize the stream water that is lost in larger water bodies. Potential water beneficial uses could include agricultural irrigation, production of hydro-electric energy, municipality water supply and wildfire suppression.

It is essential to determine the stream/torrent discharge in order to meet the above objectives. A quick, widely and frequently used technique, but also efficient application is to use hydrologic models (Singh and Woolhiser, 2002). This study describes the implementation of Soil and Water Assessment Tool (SWAT) in order to predict the torrent discharges and propose the necessary management plans to utilize the water.

The study area is the island of Thasos, located in northern Greece that belongs to Kavala Prefecture. It is the northernmost Greek island and the 12th largest by area. The surface of the island occupies about 378 km^2 while the shape of the island is almost rounded and the perimeter is approximately 102 km (Mallios et al., 2009). The terrain is mountainous; while the highest peak is Ypsarion with an elevation of 1203 m. The climate of the island is characterized as Mediterranean (Vlachopoulou and Emmanouloudis, 2014). All of the streams are characterized as intermittent or ephemeral torrents because they do not flow year around and even the major torrents (intermittent) have no flow during the summer.

2 Materials and Methods

2.1 SWAT Model Description

The SWAT model is a physically based, semi-distributed model Neitsch et al., 2011). The model predicts the impact of land management practices on water, sediment and agricultural chemical yields. It can accomplish these takes in large complex basins with varying soils, land-use and management conditions over long periods of time (Neitsch et al., 2011). SWAT processes are separated in two main components. The first one is the land phase where the hydrologic cycle in a basin is simulated based on the water balance equation (Equation 1):

$$SW_t = SW_0 + \sum_{i=1}^{t} \left(R_{day} - Q_{surf} - ET_{day} - w_{day} - Q_{gw}\right) \quad \textbf{(1)}$$

where t is the simulation period, SWt is the soil water content after the simulation period, SW_0 is the soil water content at the beginning of the simulation period, and R_{day}, Q_{surf}, ET_{day}, w_{day} and Q_{gw} are daily values (in millimeters) for precipitation, runoff, evapotranspiration, infiltration and return flow, respectively.

In the second phase the channel hydrology is simulated, more specifically the loadings that are calculated earlier are routed through the stream network of the basin (Neitsch et al., 2011). The spatial configuration of SWAT is performed by dividing the watershed into sub-watersheds based on topography. These are further subdivided into a series of hydrologic response units (HRU) based on unique soil, land use and slope characteristics.

The major benefits of the model are that it is a free product, it is applicable with the available data, it is documented well, it has good technical support through many databases and assistance programs (Gassman et al., 2007) and it has good integration with the Geographic Information Systems (GIS) through ArcSWAT (Winchell et al., 2013).

2.1 SWAT Model Set Up

The data used in this study was the topographic map of Thasos that developed based on the Military Geographic Service that had a scale of 1:50,000. This map was used to create the Digital Elevation Model (DEM) in ArcGIS 10.1 by digitizing the contour lines and the stream network (Figure 1.A.). The SWAT model requires the DEM for the creation and delineation of watersheds. There is the possibility of burning onto the hydrographic network for better results (Figure 1.B.). The next process is to fill the sinks of the DEM and calculate the flow direction and flow accumulation grids (Winchell et al., 2013). According to the properties of the DEM, SWAT proposes a minimum threshold value which represents the area (in hectares) for the establishment of the drainage area. In this study, the value of 100 hectares was selected and the island of Thasos (entire basin) was divided in 145 smaller sub-basins. Each sub-basin (or watershed) includes a stream (reach), an outlet and the simulated extension of the stream based on the DEM (longest path).

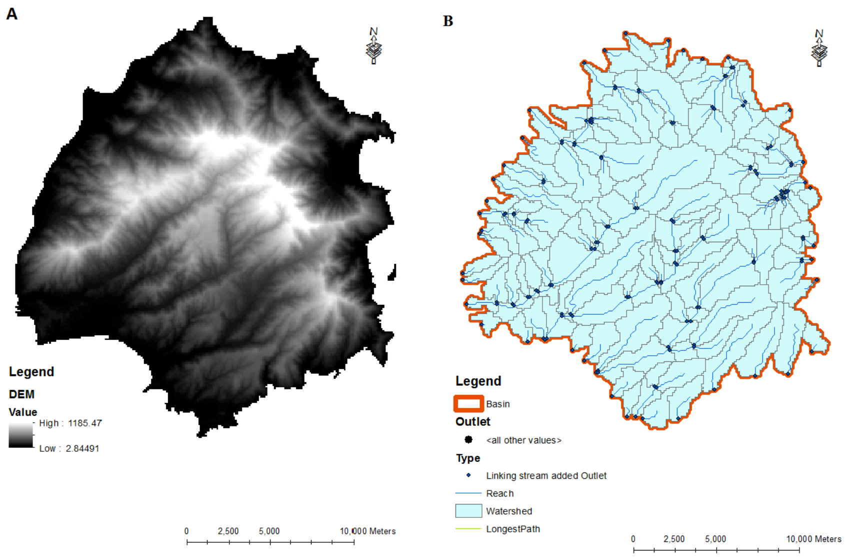

Fig. 1. The study area of Thasos Island*:* **a)** The DEM and **b)** the delineated watersheds.

Most watersheds are typically not homogenous as they consist of different soils and land-uses. As it was mentioned, SWAT can divide the watershed into smaller hydrologic response units (HRU) that are unique combinations of soil type, land cover and slope category (Arnold et al., 2012). SWAT created 2415 HRU considered all soils, land cover types and slope classes. The slope was produced based on the statistics of the DEM and it was divided into five slope classes: i) 0-10 %, ii) 10-20 %, iii) 20-30 %, iv) 30-50 % and v) >50 %.

The soil map was downloaded from the European Soil Portal and the Harmonized World Soil Database Viewer 2012 that had a scale of 1:1,000,000. In addition, the geological map was digitized and the geological parent material was considered and combined in order to create the final soil map (Table 1).

Table 1. The geologic substrate categories of Thasos

Soil Category	Geological Matter	Coverage (%)
1	Transition Zone	42.49
2	Marbles	28.63
3	Gneiss	21.09
4	Sedimentary rocks	7.79

The CORINE 2000 vector files by European Environment Agency were acquired in order to display the land-cover of the island and had a scale of 1:100,000. The land cover of CORINE was reclassified to the categories of land cover that already exist in the SWAT database (Table 2). All of these maps were geo-referenced in the Greek

Geodetic System (D_GGRS_1987). Finally, the weather data were obtained by a meteorological station located in the city of Limenas. The data concerned monthly precipitation and temperature that covered the period from 1975-1997 (Figure 2).

Table 2. The Corine 2000 land cover and the reclassification in the SWAT database.

Code	Corine 2000	Code	SWAT Database	Coverage (%)
112	Discontinuous urban fabric	URML	Urban medium low density	0.57
121	Industrial or commercial units	UCOM	Urban commercial units	0.09
131	Mineral extraction sites	UIDU	Urban industrial units	0.48
211	Non-irrigated arable land	AGRL	Agricultural land Generic	0.06
223	Olives	OLIV	Olives	9.7
243	Land principally occupied by agriculture, with significant areas of natural vegetation.	AGRR	Agricultural land row crops	6.65
311	Broad-leaved forests	FRSD	Forest deciduous	0.25
312	Coniferous forests	FRSE	Forest evergreen	22.33
313	Mixed forests	FRST	Forest mixed	0.16
321	Natural grasslands	PAST	Pastures	17.45
323	Sclerophyllous vegetation	SHRB	Shrubland	
324	Transitional woodland-shrub	SHRB	Shrubland	36.73
331	Beaches, dunes, sand	BARR	Barren areas	0.02
333	Sparsely vegetated areas	BSVG	Barren-sparsely vegetated areas	
334	Burned areas	BSVG	Barren-sparsely vegetated areas	0.49
332	Barren rocks	TUBG	Bare ground	5.02

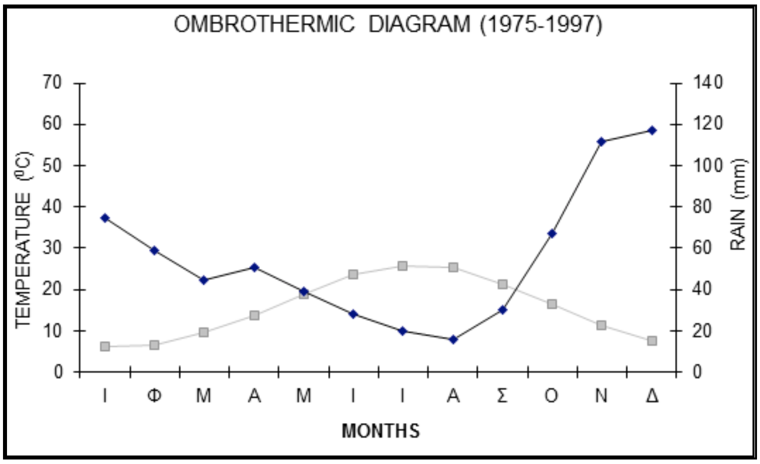

Fig. 2. The ombrothermic diagram of Limenas.

3 Results and Discussion

The simulated outputs were printed in a monthly step. The average precipitation was 844.7 mm. The results showed that most water becomes lateral flow (238.9 mm) through the soil profile because of the highly permeable soils and parent material such as marbles that allow the infiltration. The average surface runoff was about 70 mm and the groundwater flow 63 mm. These three phases consist the total water yield of the area (371.26 mm). The average percolation in aquifers was about 72 mm. There was also a high percentage of evapotranspiration (449 mm) due to the high vegetation of the island.

In addition, a map was produced (Figure 3) that identifies the average simulated stream discharges based on the outputs of SWAT. The depiction is in the view of the sub-basins/watersheds and shows which watersheds discharge had the highest amount of water. Five categories were selected based on the statistics of the flows and specifically they were divided in: i) 0-0.05, ii) 0.05-0.10, iii) 0.10-0.25, iv) 0.25-0.50 and v) 0.50-1.0 (the discharge values are in m^3/sec).

The average monthly water discharge of the major torrent is depicted in figure 4. The upper part of this torrent is situated in central Thasos while its outlet is in southeast region of the island. The specific outlet is also depicted in figure 3 as the left red colored watershed. The simulated results showed that the discharge of the specific torrent ranged between 0.04 to 1.2 m^3/sec. The almost no flow period was noted in the summer period, specifically in July and August, while the highest during November and December.

Main challenges of the study included the lack of important data. Specifically, daily weather inputs were not available, only monthly statistics were used. Observed field discharge data were not available for the calibration of the model. Also, an extensive soil map would be very helpful for the parameterization. Finally, the land cover concerns the 2000 period as Greece has not update the database. Any current satellite images could be helpful for the classification of land cover because Thasos has suffered by many fire disaster during the last 15 years.

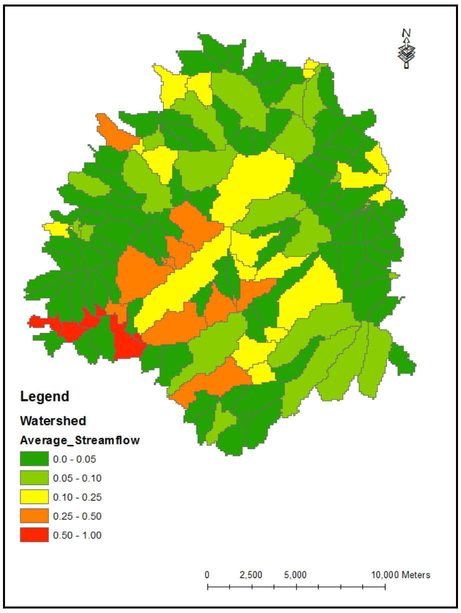

Fig. 3. The average simulated discharges of the watersheds

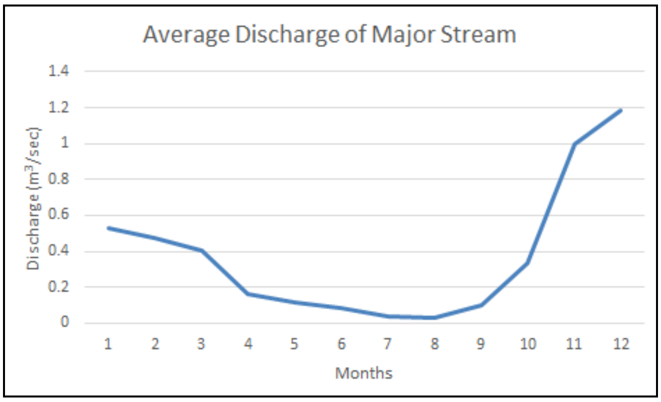

Fig. 4. The average discharge of the major stream

The results could be used for many purposes. The produced map could be a practical guide for water managers and other scientists for water resources management plans. Furthermore, future study could include the implementation of Multi-Criteria Analysis to combine other information such as wildfire maps and road network to identify best locations for water reservoirs to save water resources. The properly managed and stored surface stream water could be utilize for agricultural irrigation, the production hydro-electric power, water supply for municipalities during the summer where problems arise due to tourism and for fire suppression.

4 Conclusions

This study was an attempt to predict the water balance and the stream discharges of Thasos Island. For the specific scope, the hydrologic model SWAT was implemented to simulate the hydrologic conditions. The data used were the topographic map through the DEM, the soil map, the geological map, the land cover map and monthly weather data of the meteorological station located in Limenas. The produced results, maps and hydrographs have some limitation but could be used for water resources management plans and especially to sustainably utilize the surface torrent waters.

Acknowledgments. This research has been co-financed by the European Union (European Social Fund – ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) – Research Funding Program: ARCHIMEDES III. Investing in knowledge society through the European Social Fund.

References

1. Arnold JG, Kiniry JR, Srinivasan R, Williams JR, Haney EB and Neitsch SL, (2012) Soil and Water Assessment Tool, Input/Output File Documentation, Version 2012. Texas Water Research Institute. Technical Report 439, College Station, Texas. European Environment Agency.
2. Arthurton R., Barker S., Rast W., Huber M., Alder J., Chilton J., Gaddis E., Pietersen K., Zockler C., Al-Droubi A., Dyhr-Nielsen M., Finlayson M., Fortnam M., Kirk E., Heileman S., Rieu-Clarke A., Schafer M., Snoussi M., Tang Lingzis D., Tharme Rebecca., Vadas R., Wagner Greg., Ashton P., (Editor); Diop S., (Other contribution); M'mayi P., (Other contribution); Akrofi J., (Other contribution); Gaitho W., (Other contribution). (2007) Water, Global environment outlook 4: environment for development (GEO-4). United Nations Environment Programme, 2007. http://www.unep.org/geo/geo4/report/GEO-4_Report_Full_en.pdf

3. Corine Land Cover 2000 seamless vector data http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2000-clc2000-seamless-vector-database-4#tab-gis-data (accessed September 10th, 2014).
4. Gassman P.W., Reyes M.R., Green C. H., and Arnold. J.G. (2007) The soil water and assessment tool: Historical, development, applications and future research direction. Transactions of the American Society of Agricultural and Biological Engineers, 50(4), pp. 1211-1250.
5. Harmonised World Soil Database Viewer (2012) http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/ (accessed May 14th, 2014)
6. Mallios Z., Arapaki S., Frantzis A. and Katsifarakis K.L. (2009). Management of water resources of Thassos island in the frame of sustainable development. Proceeding of common conferences 11th of EYE kai 7th of EEDYP pp 27-34 Tomos 1 (In Greek with English abstract).
7. Neitsch, S.L., Arnold J.G., Kiniry J.R., Williams J.R. and King K.W. (2011) Soil and Water Assessment Tool – Theoretical Documentation – Version 2009.Grassland, Soil and Water Research Laboratory, Agricultural Research Service and Blackland Research Center, Texas Agricultural Experiment Station, Temple, Texas.
8. Singh V. P. and Woolhiser D. A. (2002) Mathematical Modeling of Watershed Hydrology, Journal of Hydrologic Engineering, 7(4), pp. 270-292.
9. Topographic map of Thasos (1979) in scale 1:50,000 developed by the Military Geographic Service.
10. Vlachopoulou A. and Emmanouloudis D. (2014) The contribution of hydro-informatics to the refilling capacity evaluation of small reservoirs under semi-arid conditions. Police Academy "Alexandru Ioan Cuza" – Fire Officers Faculty XVI Scientific Conference SIGPROT 2013-2014, Bucharest, Romania, pp 80-88.
11. Winchell M., Srinivasan R., Di~Luzio M., and Arnold J. G. (2013) ArcSWAT Interface for SWAT 2009: User's Guide. Texas Agricultural Experiment Station (Texas) and USDA Agricultural Research Service (Texas), Temple, Texas.