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Abstract: The purpose of this study was to model the Koiliaris River flow where flood phenomena appear from time to time. The Koiliaris River basin is located east of the City of Chania, Crete, (Greece). The basin is extended from the White Mountains (Lefka Ori) to the coastline. The geology of the basin is mainly constituted by carbonate (Karstic area), quaternary-neogenic deposits and flysch formation. The main volume of water is discharged from the karstic system of the White Mountains (Lefka Ori) through springs and temporary rivers. In order to calculate the flow from the springs the Maillet Karstic model is used. The main volume of water that is discharged to the springs through the karstic system comes from snow melt. In order to determine with high precision the rate of snow melt, a Snow melt model and the applications of GIS are combined. Using this approach the discharge from springs (for the time of the simulation) is determined. The time-series of the karstic discharge from the springs is entered in the code of the Hydrological Simulation Program - FORTRAN (HSPF) model, in order to calculate both the surface and subsurface discharge. The HSPF is a set of computer codes that simulate the hydrologic process. The hydrologic model of HSPF functions in the frame of the BASINS 4 model. The final step is the Calibration and the Sensitivity analysis of the HSPF model. The main objective of the present study is to develop a tool for the prediction and management of flood events that occur in the area.

Keywords: GIS; HSPF model; Karstic area; Koiliaris River basin; Snow melt.

1. INTRODUCTION

One of the main disantvantages of the models estimating the river flow is the fact that very often the contribution of the groundwater flow is ignored. The contribution of this kind of flow can be significant especially in cases where the geological formation is characterized as karstic. In the karstic areas most of the surface runoff and the snowmelt water quantity becames groundwater flow which can be realized farther down the flow direction in the form of springs. Also, this groundwater flow in many cases becames a significant contribution to the main river flow. In the present study, the HSPF model in combination with a snow melt model was employed to compute the surface and groundwater flow contributions to the Koiliaris River flow (Jaquet et al., 2004).

2. KOILIARIS RIVER BASIN

2.1 General Characteristics

The Koiliaris River basin is located 15 Km east of the City of Chania, Crete and is extended from the White Mountains (Lefka Ori) to the coastline. The area of the basin has been estimated to be approximately 130 km^2. The elevations of the basin range from zero to 2120 m ASL (Figure 1). The total length of the Koiliaris River network is 36 km. From the intersection point, where all the streams met, to the outflow point the length of the river is 3.3 km. In 2005, a hydrometric station was installed at the location Agios Georgios in order to monitor the flood events. The rainfall data of the study area have been collected from the raingauge station of Kalibes, which is close to the river and located at an elevation of 24 m ASL (Figure 2).

2.2 Hydro Geological Characteristics

The topography of the area of interest is smooth with a mild topographic slope of 12%. The geology of the basin is mainly constituted by carbonate, quaternary-neogenic deposits and flysch formation. Based on a former research project, conducted by the Ministry of Agriculture of Greece, it has been estimated that 58% of the total land use of the basin is characterized as pasture (public or private), 29.4% as crops, 2.8% settlements and roads, 8.5% as forests, 0.6% as water surfaces and 0.7% as other uses.

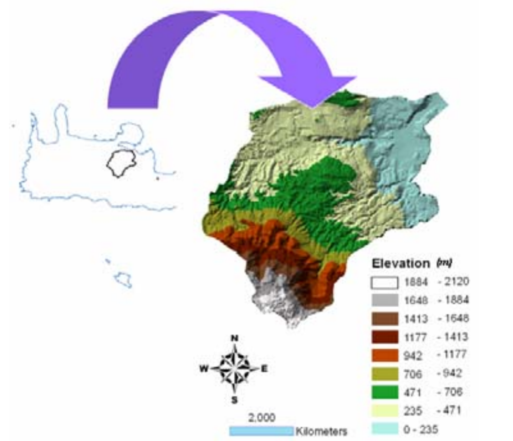

Figure 1. The island of Crete and the Koiliaris River basin.

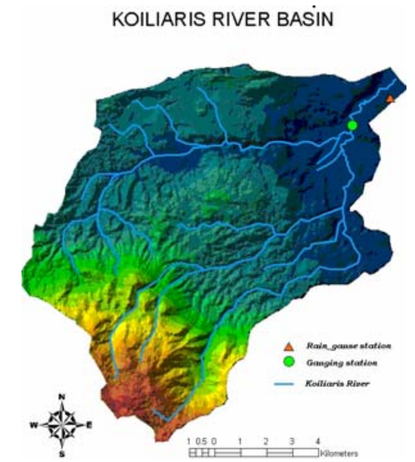

Figure 2. The hydrometeorological network of the Koiliaris River

2.3 Temperature – Rainfall gradient of the Koiliaris River basin

Until 2007, in the Koiliaris River basin there were not a sufficient number of meteorological stations. Therefore, in the present study the meteorological information was obtained from stations located in the surroundings of the basin area. Since the Koiliaris River basin is small it is considered that data from the surrounding the basin stations can be used for the present study. These stations are even distributed regarding altitude, land-planing and have continuous measurements of the meteorological parameters for a long time period. The nearest meteorological stations used in the present analysis were the meteorological stations of Souda, Kalibes, Askifou, Brises and Chania.

Through the analysis of the meteorological data from the above stations the monthly temperature change and the annual rainfall change were estimate, for the North-East part of the Prefecture of Chania, where the Koiliaris River basin is located. The meteorological data were for the time period between the years 1975 and 2006, (Table 1, Figure 3).

Table 1. Average monthly temperature change with the altitude in the Koiliaris River basin.

Monthly temperature change per 100m altitude											
Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
0.82	0.75	0.74	0.56	0.25	0.26	0.17	0.72	0.62	0.68	0.93	0,7

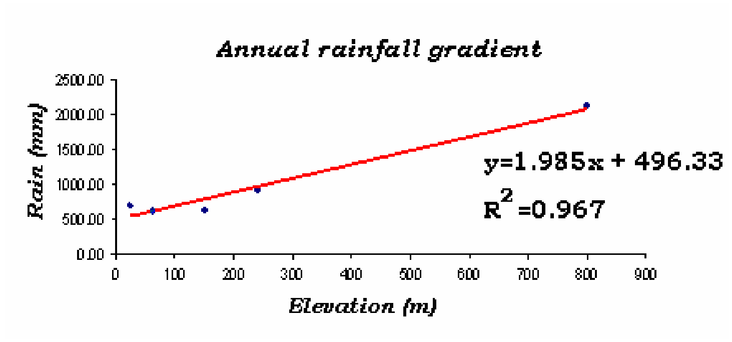

Figure 3. Annual rainfall gradient according to the altitude, for the North-East part of the City of Chania.

3. THE KARSTIC AND SNOW MELT RATE MODEL

In the present study the conceptual model considers the following:
The main volume of water in the area of study is discharged from the karstic system of the White Mountains (Lefka Ori) through springs, streams and temporary rivers. In the Koiliaris River basin three main karstic discharge points exist: the Stilos, the Armenoi and the Zourbos springs. The Stilos spring is one of the main water sources and the major discharge point of the karst system of White Mountains and it is considered to be the main water source of the Koiliaris River.

The Kartic model used was the stochastic Maillet karstic model. The reason for choosing Maillet's model is that it has a physical meaning; it is based on the hydrologic balance equation during the recession period and takes into consideration springs discharges at specific points (the case of Stylos spring). The Karstic system of the Koiliaris River was considered as a two reservoir system (Stamati et al., 2006). The analysis of the above system suggests the existence of "two reservoirs" within the karstic system; the upper reservoir with a faster response (wide conduits), and the lower reservoir with a slower response (narrow fractures). A 'two part' Maillet model was developed representing the upper and lower reservoirs (Figure 4).

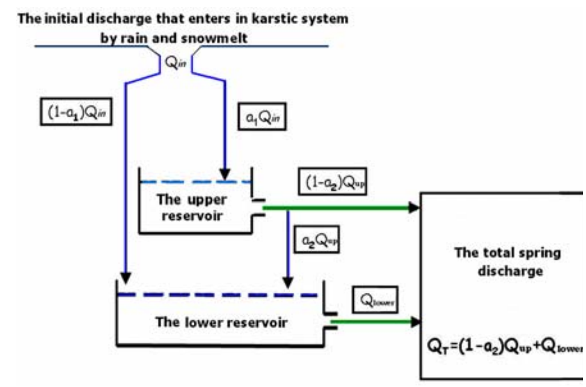

Figure 4. Graphic description of the Karstic model.

The formulation of the karstic model of Maillet is:

$$Q_T = (1-\alpha_2) * Q_{up} + Q_{lower}$$

$$Q_{up} = Q_{up-1} e^{-k_u \Delta t} + a_1 Q_{IN} (1 - e^{-k_u \Delta t}) \qquad (1)$$

$$Q_{lower} = Q_{lower-1} e^{-k_l \Delta t} + [a_2 Q_{up} + (1-a_1) Q_{IN}](1 - e^{-k_l \Delta t})$$

Where:

Q_T is the total spring discharge, Q_{up} and Q_{lower} are the initial discharge contributions of the upper and lower reservoirs respectively, Q_{IN} is the initial discharge that enters in karstic system, α_1 is the percent of the water (rain and snow melt) that enters in the upper reservoir and α_2 is the percent of discharge that enters from the upper to the lower reservoir, k_u and k_i (1/d) are the recession coefficients of the upper and lower reservoirs respectively. Moreover, the time step (Δt) of the model is equal to 1 day, (Tzoraki et al., 2006).

The parameter Q_{IN} includes apart from the rainfall the daily rate of snow melt. The daily rate of snow melt is calculated by empirical equations. These equations are developed by the U.S. Army Corps of Engineers (1956) and have been applied in many flow basin models, (Nikolaidis et al., 1988):

A) Snow melt equation during the dry period:

$$M_s = C_{m1} * (1.8 * T_a)^{n+1} / 1000 \qquad (2)$$

B) Snow melt equation during the rain period:

$$M_s = C_{m2} * (0.007 * P_w + 0.074) * T_a * 1.8 + 0.05) * 0.254 / 1000 \qquad (3)$$

Where:

Ms is the snow melt rate (m/d), C_{m1} is the snow melt factor ($md^{-1}C^{-1}$), C_{m2} is the snow melt factor adjusted to local conditions (dimensionless), n is the coefficient with the value of 0.25, P_w is the daily rate of rainfall in (m/d), and T_a is the average daily air temperature in (^oC).

3.1 The Karstic area and snow melt zones

Stilos spring discharges at 17 m ASL and have an intense seasonal fluctuation in its discharge. The average annual discharge is $73*10^6$ m^3/yr (hydrologic years 1970-2006). In addition to this the average annual discharge of Armenoi and Zourbos springs were taken into consideration which are $27*10^6$ m^3/yr and $26*10^6$ m^3/yr respectively, (Figure 5). The above values of discharges were considered as an input to the Maillet karstic model and by using the trial and error technic it was possible to determine the extent karstic area that contributes to the spring discharges in the area of Koiliaris River basin. Based on this approach and after the calibration of the Maillet karstic model, the extent karstic area that contributes to the above water volume was estimated to be 138 km^2. Due to the lack of previous data a geological study was performed in order to determine the karstic area. Based on this study it was found that in the area of interest two main karstic faults exist. These faults are connected as it is shown in Figure 5. Accordingly to this, the estimated extended karstic area that contributes to the discharge of the above springs appears in Figure 5.

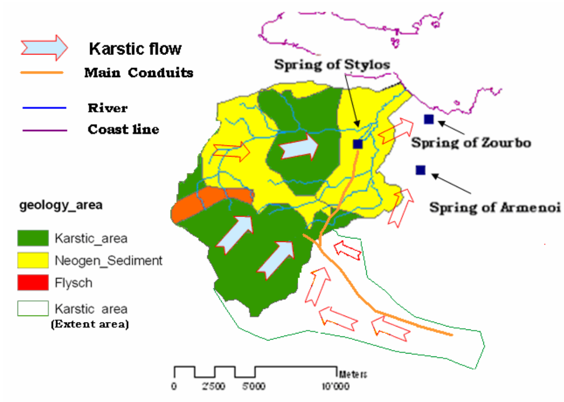

Figure 5. Territorial distribution of the geology and the springs of the extent area of Koiliaris river basin.

The karstic model of Maillet incorporates the equations of the snow melt rate. These equations take into account the quantity of rainfall, and the air temperature, (Yang et al., 1997) but they do not consider the topography of the area and the intensity the solar radiation. In order to take these two terms into consideration GIS was used. The territorial mountainous area was divided into 5 different zones that were characterized by 5 different snow melt rates (very low, low, medium, high, and very high), (Shaban et al., 2006). The final map of territorial snow melt rate was created based on the topographic characteristics and the intensity of solar radiation

The areas and the average altitudes of the 5 different snow melt zones were computed with the use of GIS. Using the Weighted Moving Average of each area with their corresponding altitudes, the average altitude of the total karstic area was determined to be 1400.41 m. The computed daily rainfall and temperature data were imported to the karstic model. Based on this, the discharge from Stylos spring was computed and used as input to HSPF. The HSPF model has the ability to simulate the surface flow from the basin to the river. The final objective was a more accurate simulation of the Koiliaris River basin flow (surface and groundwater).

4. THE HSPF MODEL

The Hydrological Simulation Program - FORTRAN (HSPF) is a set of computer codes that simulate the hydrological and associated water quality processes on pervious and impervious land surfaces, in streams and well-mixed impoundments. The model simulates the time response of the watershed based on the hydrological and geochemical mass balance and the wet and dry depositions to surface water. The HSPF model is a physically based model that incorporates GIS data (Bicknell et al., 2001).

4.1 The Hydrology of the HSPF model

The HSPF model considers that in the river a complete mixture takes place and that the flow is uniform. It takes into consideration the equation of continuity:

$$VOLE = VOLS + sumIVOL - sumOVOL + PR\text{-}EVAP \qquad (4)$$

Where:
VOLE= volume of water at the end of the time step, VOLS= volume of water at the beginning of the time step, IVOL= inflow volume, OVOL= outflow volume, PR= rainfall volume, EVAP= evaporation volume. The OVOL is computed as:

$$OVOL= \Delta t\ (KS*OS+(1\text{-}KS)*OE) \qquad (5)$$

Where:
KS= gravity coefficient with values between 0.0 – 0.5, OS= outflow at the beginning of the time step and OE= out flow at the end of the time step

Substituting Eq. [4] into Eq. [5] yields:

$$VOLE = VOLS + sumIVOL + PR\text{-}EVAP\text{-}[\Delta t\ (KS*OS + (1\text{-}KS)*OE)] \qquad (6)$$

In Equation [6] the only unknown parameter is the OE, which can be calculated using the FTABLE table that connects the geometry of watercourse of the sector with the flow (Bicknell et al., 2001).

4.2 An application of the hydrologic model HSPF to the River basin for the time period 09/01/2006 to 01/05/2007

The HSPF model operates in the frame of the BASINS model. The new edition (2007) of the BASINS 4 model was used. The BASINS 4 model has the potential to divide the basin into sub-basins, so that the hydrology of the entire basin to be simulated with more accurate precision. The essential geographic information required by BASINS 4 model was the watershed, the sub-basins, the hydro network, the uses of land and the elevations. This information was supplied to the model using GIS. In the present work the basin of the Koiliaris River was divided in 6 sub-basins, (SWS), (Figure 6).

Figure 6. Segregation of the basin into 6 sub-basins in the environment of the BASINS 4.

The main criteria of selecting these 6 sub-basins were the uniform hydrological, topographical, geological and land-planning characteristics. The above sub-basin information becomes the input for the BASINS-4 model which creates data files in the form that HSPF model requires. Also, by using the Watershed Data Management (WDM) program all the meteorological time series are logged on and used for running HSPF. For each sub-basin different time series were used regarding the temperature and the rainfall. These time series are related to the annual rainfall gradient and monthly temperature gradient for the region of interest. Specifically, the average altitude of each sub-basin was calculated and then the daily rainfall and temperature were determined using the hypsometric method. The evaporation was calculated by the Penman method using the WDM program that considers the data of the daily rainfall, relative sunlight, relative humidity, and temperature.

Regarding the solar radiation the only available data were from the meteorological station of Chania, which started to operate on 09/01/2006. Based on this, the hydrologic simulation was performed for the time period of 09/01/2006 to 01/05/2007. During this time period hourly data for the flow were also available from the hydrometric station of Agios Georgios (in the SWS 1), which assisted the calibration of the HSPF model.

All the input requirements for all sub-basins were provided to HSPF model using the Basins 4 model. The time-series of the karstic discharge from the Stylos spring were entered in the code of the User Control Input (UCI) file of HSPF, in order to calculate both the surface and underground discharges.

Following the simulation the process of calibration of the parameters was performed. The simulation results were introduced to the BASINS model for analysis using the tool Scenario Generator (GenScn).

The following parameters were used for the calibration (Kim et al., 2007):
a) The LZSN: is the lower zone storage nominal, b) The UZSN: is the upper zone storage nominal, c) The INFLT: is the soil infiltration rate, d) The LZETP: is the lower zone of evapotranspiration, e) The AGWRC: is the groundwater recession rate, it is rate of the groundwater discharge.

4.3 The Results of simulation of the HSPF model

In order to compare the field data with the simulated ones the Root Mean Squared error (RMSE) was used, defined as:

$$RMSE = \sqrt{\frac{1}{n} * \sum_{i=1}^{n} R_i^2} \qquad (7)$$

Values of RMSE close to zero indicate perfect fit and the model calibration is considered satisfactory only when RMSE < 3.0. For the above case the RMSE = 2.58. The Figure 7 shows the comparison between the simulated results (HSPF model) and the observed data for sub-basin 1.

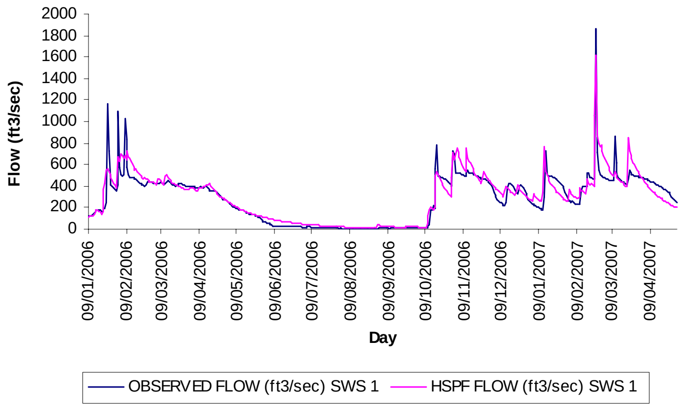

Figure 7. Comparison of simulated and observed flow for sub-basin 1.

4.4 The Sensitivity Analysis of the HSPF Hydrologic Model

After the calibration of the HSPF model was completed, the sensitivity analysis was performed to study the sensitivity of the calibrated results in comparison to field data (Al-Abed et al., 2002). In order to accomplish this, the main hydrological parameters of the calibration were disturbed by ±10%, in order to calculate the sensitivity of each parameter. The sensitivity analysis was only performed for the 'Coastal sub-basin' SWS 1, since it was the only sub-basin with field measurements. The sensitivity index S used in this part of the study is defined as:

$$|S| = (Q_{new} - Q_{calibrated})/(K_{new} - K_{calibrated}) \qquad (8)$$

Where:
$K_{new,}$ $K_{calibrated}$ is the new and calibrated value of each respective hydrological parameter (K) of the HSPF model and $Q_{new,}$ $Q_{calibrated}$, are the simulated values for $K_{new,}$ and $K_{calibrated}$ respectively. The lowest the value of S the less the sensitivity of the parameter is.

The results of the sensitivity analysis for the most important parameters of calibration are summarized in Table 2. The highest sensitivity appears for the parameter INFILT followed by UZSN, and LZSN.

Table 2. Sensitivity Analysis of main parameters of model calibration

Sensitivity Value of INFILT	Sensitivity Value of UZSN	Sensitivity Value of LZSN
0.59	0.09	0.02

5. CONCLUSIONS

The aim of this study was the modeling of the hydrologic activities of the Koiliaris River basin (Prefecture of Chania, Crete). The preliminary results of the simulation, using the HSPF model, have shown that there was not a good agreement between the simulated and observed data. This is due to the karstic geomorphology of the system which has a significant contribution to the Koiliaris River flow in the form of groundwater flow. In order to improve the agreement between simulated result and field data the HSPF model was combined with the 'two part' Maillet Karstic model which also considers the snow melt rate. As it was expected the snow melt rate has an important role to the final form of hydrograph. The final results of the above simulation showed a very good agreement with the observed field data. Since in the area of study flood phenomena occurred from time to time the present model could become a useful tool for the prediction of a flood event and for the better organization of a flood management plan.

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