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Research Article

A water balance model of the Natura 2000 protected area "Nestos delta"

D. Myronidis and D. Emmanouloudis*

Dpt of Forestry and Natural Environment Management, TEI of Kavala, Drama 66100, Hellas.

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Abstract

The purpose of this paper is to develop the water balance of the Natura 2000 protected area "Nestos delta" on a monthly time step. The most significant ecosystem of the delta is the aquatic forest (dominated by *Salix alba* and *Populus alba*) which remains along the river course near the mount and the poplar plantation. During the last decade two large dams have been constructed upstream of the study area for hydropower generation and irrigation, resulting in the dramatic modification of the hydrologic regime of the site. The research is based on the analysis of the available geographical and hydrological data of the study area for the period 1985-2006. Through the integration of Geographical Information Systems (G.I.S.) and computational hydrology techniques, the water balance of the study area is constructed and the need of decision making has raised in order to prevent further deterioration of the unique aquatic forest.

Keywords: Water balance model, GIS, Nestos delta, Surplus

1. Introduction

The water balance of basins constitutes a matter of fundamental importance in hydrogeological and hydrological research and has engaged the scientists for many decades [1]. Water balance models were first developed and applied in the 1940s and 1950s by Thornthwaite [2] and Thornthwaite and Mather [3]. These original models were essentially monthly bookkeeping techniques that tracked the balance between the inflow of water from precipitation and snowmelt and the outflow of water by evapotranspiration, streamflow, and groundwater recharge. Their simplicity and ease of applicability have made them appealing [4].

The original Thornthwaite-Mather model has been applied from various researchers for small [5-6] or large scales [7] and for various time steps [8-9].

With the advent of increasing computing power and GIS technique, physical-based hydrologic modeling has become important in contemporary hydrology for assessing the impact of human intervention and/or possible climatic change on basin hydrology and water resources [7].

This paper presents an attempt to model the water balance of the "Nestos delta" Natura 2000 protected area, whose hydrology has been significantly affected from the construction of the dams upstream. Thus, the paper doesn't concern the groundwater aquifer and the problems that arise from the seawater intrusion into it, due to the over exploitation of the water resources. Knowing that the water inflows in the study area are regulated from the hydropower station and the water is channeled through irrigation canals, our research is focused only in the water balance of the Natura area and it also does not concerned the river inflows in the current research. The main factors that are reported to cause degradation of aquatic forests are either the construction of hydropower and irrigation dams upstream resulting in a significant reduction of their supply or the excessive pumping of their ground water aquifers from the delta where these forests are located [10].

Dam construction generally results in a reduction of peak flows, which reduces the ability of the stream to carry sediments. The decrease in the water yield and the sediment load led to significant changes in the area and shape of the delta [11] and considerable disturbance of the biotope [12]. Flow regimes can also be altered through regulation, in terms of the duration of flows of a given magnitude, the total annual discharge, flow variability, or the frequency of flood peaks. The altered flow regimes can influence oxygen levels, temperature, suspended soils, as well as have direct impacts on biota [13].

2. Study area description

The "delta Nestou" Natura network site (GR 1150001) encompasses an area of 111km^2 in N. Greece (Fig. 1). This designated site is a large Delta and consists almost entirely of agricultural land with few freshwater lagoons separated from the sea by narrow sandy strips and a unique aquatic forest protected according to the Ramsar convention. The dominant forest trees are the Salix alba and Populus alba. Most of the area of Nestos River is embanked by retaining dykes to be separated from the cultivated land. The average elevation of the study area is 5m and the average annual rainfall is 457 mm/year with 90 days of rain annually. The

* E-mail address: demmano@teikav.edu.gr

annual temperature is 15.4°C and the climate of the study area is characterized as Mediterranean type, with soft winters and dry, hot summers.

Two major dams have been constructed upstream for hydropower generation and irrigation. These two dams (Thisavros and Platanovrisi) produce a total of 665 GWh and regulate the river flow to the delta. For environmental conservation reasons, it was decided that the Delta should receive at least 6 m³/s. Water is mainly used for hydro-energy production and irrigation purposes and it is less exploited for urban and industrial use [14]. At least 2,000 shallow drills exist in the area.

Fig. 1 Location map of the study area

3. Materials and Methods
3.1 Materials

To apply the Thornthwaite and Mather water balance model, a spatial vector-type geodatabase containing topography, soil, land use and meteorological information was constructed. Toposheet of the Hellenic Military Army Service (HMAS) on a scale of 1:50,000 were used to create the contour map and the drainage network of the study area in ArcGIS software. The geology map of the site was obtained from the Hellenic Institute of Geology and Mineral Exploration (IGME) 1:50,000 maps. Land use and land cover of the study area were extracted through high-resolution remote sensing data obtained from Digital Globe.

An area of 27 km^2 was captured from Quick Bird imaging system during December 2003. The image was geometrically and spectrally corrected in lab, and an orthorectification process was applied in order to provide the highest degree of geometric accuracy. The data of the “Xrisoupoli National Airport” rain gauge located near the examined area was used. The data was collected during 21 consecutive water years (1st of October 1985 to 30th of September 2006) and is comprised from mean monthly temperature (T, in degrees Celsius) and monthly total precipitation (P, in millimeters) for the period mentioned above [15].

3.2 Methods

Monthly Potential Evapotranspiration (PET) is estimated from average monthly temperature (T) and is defined as the water loss from a large, homogeneous, vegetation-covered area that never lacks water [2]. Thus, PET represents the climatic demand for water accordingly to the available energy. In order to calculate the amount of precipitation that evaporates or transpires back to the atmosphere we used the generally accepted method proposed by Thornthwaite and Mather [16].

$$ET = 16\left(\frac{10t_n}{J}\right)^a \cdot L_d \quad (1)$$

$$a = 0.016\,J + 0.5 \quad (2)$$

$$I = \sum_{n=1}^{12}\left(\frac{tn}{5}\right)^{1,514} \quad (3)$$

Where, tn = mean monthly temperature and Ld = coefficient depending on the and the latitude (in decimal degrees) of the location of interest.

The Potential maximum soil moisture retention after runoff begins (So) is a parameter related to curve number [17-18] and is computed as:

$$So = \frac{25400}{CN} - 254(mm) \quad (4)$$

A curve number (CN) is an index that represents the combination of a hydrologic soil group and a land use and treatment class and has a range of 30 to 100. Lower numbers indicate low runoff potential whereas larger numbers demonstrate an increasing runoff potential. SCS developed a soil classification system that consists of four groups, which are identified by the letters A, B, C, and D [19].

There are tables from USDA Soil Conservation Service [17, 20] that indicate CN for characteristic land cover descriptions and a hydrologic soil group. The Hydrologic Studies Unit (HSU) of Michigan’s Department of Environmental Quality (MDEQ) method [21] was employed to compute CN from GIS land use and soils information.

- When P for a month is greater than PET, there is reconstitution of soil which is reserved until saturation; the surplus represents the superficial or groundwater flow

$$Si = \min((Pi-PET)+Sn-1, So) \quad (5)$$
$$DQ = (Pi-PET)+(Si - So) \quad (6)$$
$$Ri = (1-\kappa)(Qn-1 + DQ) \quad (7)$$
$$Ii = \kappa(Qn-1 + DQ) \quad (8)$$

- When P for a month is less than PET, it pumps from the soil reserves. When the stock is null, the evaporation will equal the rainfall

$$Si = S_{i-1} \exp[-(PET-Pi)/So], \quad (9)$$

Then a water deficit is calculated as;

$$Di = So - Si \quad (10)$$

Where, Si: monthly soil moisture, Pi: monthly precipitation, So: Maximum soil retention, AET = Actual Evapotrasnpiration, DQi =Water surplus, Ri= monthly runoff, Ii= monthly groundwater recharge, κ = runoff coefficient [21].

4. Results and discussion

The first step in the model application is to determine the interaction between the recorded precipitation (P) and PET that is calculated from eq. 1 (Fig. 2).

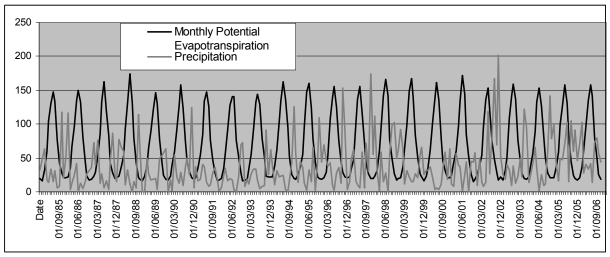

Fig. 2 Precipitation – Potential Evapotrasnpiration diagram (mm/month)

In order to compute the CN [22] we classify the soils of the study area into hydrologic soil groups according to their infiltration rate while land use classification was based on the Anderson Level II land use coding [23] (Fig. 3).

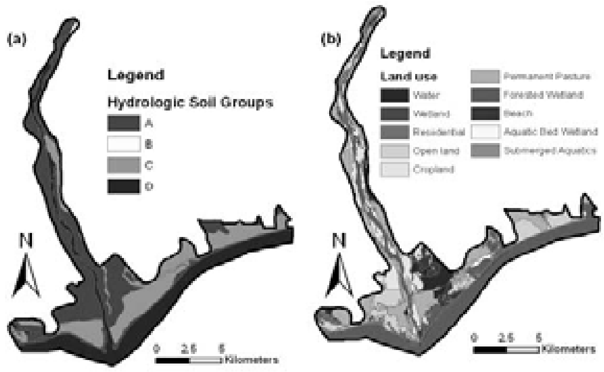

Fig. 3 Land use (a) and Hyrdologic soil groups types (b) of the study area

Then, a number less than 100 was assigned to each land category and a number that is a multiple of 100 to each soil category. The two numbers are summed and the CN is associated with each summed number. A composite CN equal to 73 was calculated using area-weighted averaging [24].

Finally, the results of the annual runoff which were derived from the application of the model are displayed in the following fig. 4. Furthermore the mean monthly surplus was computed at 4.4 mm/month while the ecosystem water requirements are estimated at 750mm/hr or 62.5mm/month [25, 26].

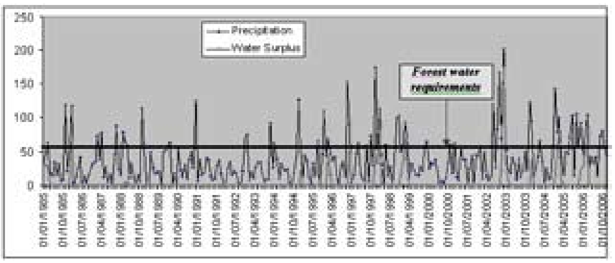

Fig. 4 Monthly surplus for the study region (mm/year)

5. Conclusion

The conclusions from the accomplished study of the Nestos Water balance are recapitulated as following:

- a soil water balance was constructed using monthly climate data and GIS techniques. The inputs to the soil water balance are monthly precipitation and air temperature. The outputs are monthly water surplus (runoff or recharge), evaporation and soil moisture level.
- the average values of the monthly surplus are very low for the study area and they are usually reach at zero during the summer months, when the requirements of the protected forest are maximized. These amounts of surplus do not ensure the sustainable development of the site.
- The rapid and almost uncontrolled growth of population has resulted in continuously increasing water demands for agriculture purposes in the study area.
- The main problem of the area is that although the study area is an aquatic forest and the whole delta used to flood regularly in the past, this can't be achieved today in order to obtain the desirable runoff and recharge because it is regulated from the big hydroelectric plants that have been constructed upstream.
- In the case of "Nestos delta" it is recommended to increase the available water discharges from the hydroelectric plant with a simultaneously decrease on the irrigation for crops of the area.
- Finally, climate change scenarios predict that next decades the temperature will be increased with simultaneously decrease in precipitation for the Mediterranean basin resulting further deterioration of the water balance [27].

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