HYDROLOGIC AND BIOGEOCHEMICAL MODELING OF A TYPICAL TEMPORARY MEDITERRANEAN RIVER BASIN

O. Tzoraki and N. Nikolaidis

Technical University of Crete, Department of Environmental Engineering, 73100 Chania, Greece, E-mail: utzoraki@mred.tuc.gr, nnikolai@mred.tuc.gr

ABSTRACT

Results from an integrated observational and modeling study of a typical Greek temporary river are presented. The mathematical model Hydrological Simulation Program – Fortran (HSPF) was used to simulate the hydrology, sediment transport and nutrient loads of Krathis river basin. The model simulated the time response of the watershed based on geochemical and hydrologic mass balances. The model captured the seasonal variability of the flow and the concentrations of suspended solids and nutrients. Finally, the calibrated model was used to simulate the effect of climate change to the hydrology and geochemistry of Krathis river basin.

1. INTRODUCTION

The Mediterranean region is characterized by a variety of microclimates ranging from humid, to semi-arid [1]. The dominant types of rivers are temporary. Temporary rivers are natural bodies of water that experience a recurrent dry phase of varying duration and spatial extend [2]. In contrast to their temporal character, temporary rivers support ecological systems that have been used by biota and people for millennia. Temporary rivers provide a challenge for sustainable water management and the application of the Water Framework Directive (WFD-200/60/EC) because they cover 26 % of the south Mediterranean terrestrial area [3].

The majority of the temporary rivers are found in ungauged basins. There are little to no data regarding their hydrologic and biogeochemical regime. In addition, most of the temporary rivers especially in the dry period are used as uncontrolled waste disposal sites. There are no management plans or special practices that could protect the water quality and sustain the ecological quality. On the other hand, temporary rivers have the same uses as the permanent. They are used for water supply, irrigation, hydroelectric power generation etc.

Modeling a temporary river is very challenging. First of all, lack of data makes the study of the catchment very difficult [4]. In addition, a large number of temporary rivers in the Mediterranean region are located in karst areas. Karstic aquifers discharge in springs that feed the temporary rivers with baseflow. Karstic baseflow can not be modelled by traditional watershed models, comprise an important component of river hydrology and should be included in the hydrologic models [5].

During dry periods, temporary rivers have no flow and their riverbeds are completely dry. Most of the existing models can not simulate no flow conditions. On the other hand, in temporary environments the river bed is expanding in the winter during the flooding events and is contracting during the dry period. The expansion and contraction of the river bed affect the ecotopes and the processes in it. The expansion – contraction of the river bed is not included in hydrologic and geochemical models [6]. During the first flush and the following rain events discharge, sediments and nutrients concentrations are high compared to baseflow conditions. Rain events stimulate pulses of biological and biogeochemical activity that are often short lived and this activity continues during extended dry periods [7].

The overall objective of this study was to simulate the hydrologic and biogeochemical regime of a typical temporary Mediterranean river basin, Krathis river basin. The mathematical model Hydrological Simulation Program – Fortran (HSPF) was used to simulate the hydrology, sediment transport and nutrient loads of Krathis river basin. HSPF is a distributed parameter, physically based model that is used to simulate the hydrologic and geochemical regime of a temporary river [4].

2. METHODOLOGY

The general parameterisation procedure [4] included parameters that were associated with measurable catchment characteristics (soil types, vegetation, climate, geology etc) and parameters that were assessed from field data and need calibration. These parameters are estimated with topographic maps, field surveys, photographs and site visits. The study site was Krathis River located in northern Peloponnesus, Greece (Figure 1). The catchment covers an area of 149 km^2. The main part of the basin is mountainous (mean altitude = 1092 m), resulting in a mean slope of 33 %. Forests cover 75.4 % of the watershed, while the cultivated areas cover 24.4 %. The length of the river is approximately 30 km. The dominant formations in the catchment are neogene and quaternary sediments (60 %) limestone (22 %) and flysch (18 %) [6]. In summer, the river at its lower portion, dries out due to the combined action of draughts and water abstraction for irrigation. The mean annual precipitation ranges from 700 mm at the coastal zone to 900 mm on the mountainous zone [6]. The total population of the basin is 7056 and the population density is approximately 47 citizens per km^2. Human impacts concern mainly diffuse pollution, originating from agricultural activities and two point pollution sources; one fish farm and a solid and wastewater disposal site, which also receives the municipal wastewaters of the town of Akrata. Finally, most of the villages use septic tanks.

Model description: HSPF is a comprehensive, physically based hydrologic and geochemical model that has been applied to many watersheds in North America and Europe. It can simulate rivers, lakes, reservoirs and ground water [8]. It has been recently modified to include irrigation and best management practices. It is a comprehensive model that allows the integrated simulation of land and soil contaminant runoff processes with in-stream hydraulic, water temperature, sediment transport, nutrient, and sediment-chemical interactions. The hydrologic processes include precipitation, evapotranspiration, interception, storage, surface runoff, infiltration, percolation, interflow and groundwater. The runoff quality capabilities include soil process options (i.e., leaching, sorption, soil attenuation and nutrient transformations).

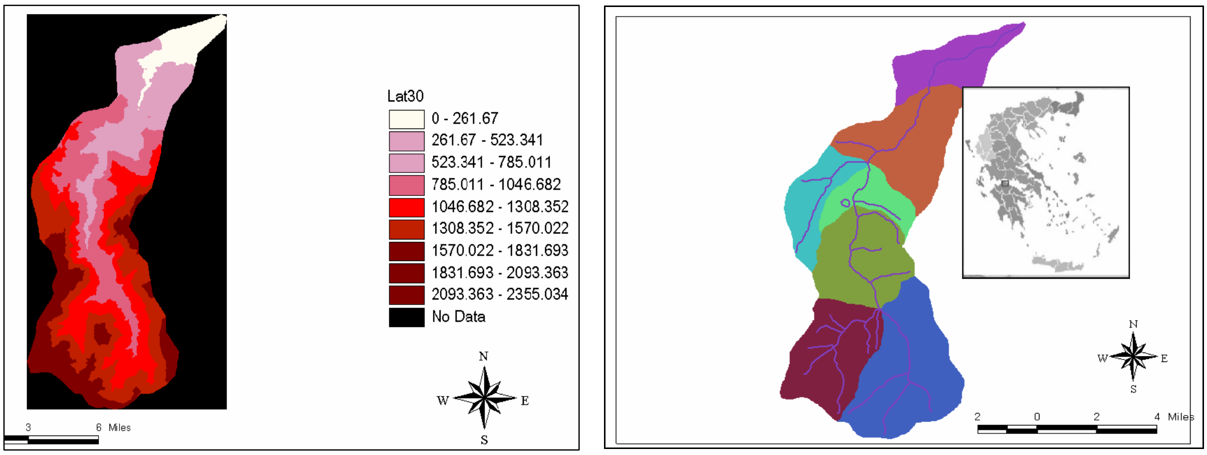

Figure 1: A. Digital elevation model, B. Subcatchment map and river network of Krathis river basin.

Stochastic spring flow: Krathis river watershed consists of a dense network of springs that contribute to the river base flow, especially during the summer period. There are two separate hydrologic pathways that operate in the basin. The first pathway is the base-flow provided by the karstic system and the second pathway is the runoff provided by the shallow, high slope and low infiltration thin soils. The karstic base-flow is supported by springs and it is operating independently from the surface system. The runoff data for the dry period of 2003 is used in order to develop a stochastic model of the karstic flow: $Q_{karstic} = Q_0 *e^{(\pm kt)}$, where Q_0 is the flow at the start of the wet or the dry period and k is a recession coefficient equal to 0.0052/sec. This model was used to generate baseflow data that were imported into HSPF.

Calibration methodology: The hydrologic and geochemical calibration of Krathis River Basin was conducted using the dataset from July 2003 to Oct. 2004 collected by Hellenic Centre for Marine research (HCMR) as part of the tempQsim project [6]. Annually, the catchment receives 252.2 tn of N and 118 tn of P as inputs. Agriculture contributes 63% of the N load and 92% of the P load. Livestock production contributes 5% of the N load and 2% of the P load. The atmospheric load contribution of N is 27% of the total load and 3% of the total P load. Finally, point sources contribute 5% of the N and 3 % P loads. First the hydrologic calibration was conducted; second the sediment transport and finally the water quality calibration. Once the model was calibrated, the climate change scenarios were for the years 2020, 2050, and 2080 were simulated.

3. RESULTS

Hydrology: The 2003- 2004 dataset were used for the hydrologic simulation of the catchment [6]. Snow records were used from the meteorological station at Drosato Achaias (elevation of 800 m) for the periods of February –March 2003 and January- February 2004. Figure 2 presents a comparison of model simulation with field data for subbasin 6 which is the outlet of the basin. The Root Mean Square Error (RMSE) was estimated to be 1.15 m^3/s and the average model flow was 2.7 m^3/s while the average field flow was 2.6 m^3/s. The standard deviation for the field data was estimated to be 2.9 m^3/s and for the model data 2.5 m^3/s. Residuals between model versus field flows had a positive trend. Only in the high flow values there was a difference between field and model data. The mean values were similar, the Nash Sutcliffe efficiency (a measure of the quality of the model with respect to the representation of the variance of the data) was estimated to be 0.84. A value of 1 means perfect representation. The efficiency was strongly affected by a few extreme errors and were biased because the range of flow events was very wide. The Kolmogorov-Smirnov test compared the (cumulative) distributions of 2 data series and results for Krathis indicated an observed bias for the high flows.

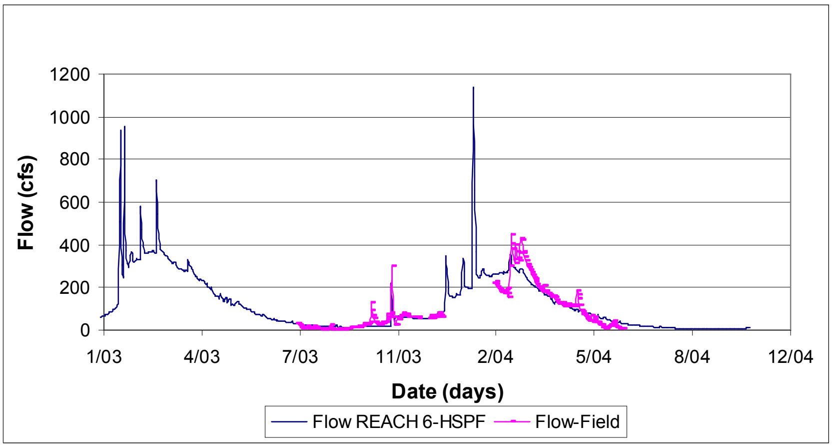

Figure 2. Hydrologic simulation of Krathis river and comparison with field data.

Sediments: Figure 3 presents a comparison between modelled suspended sediments concentration and the field measurements. The RMSE was estimated to be 183.4 mg/L at the river outlet, where the average model suspended sediment concentration was 163.1 mg/L. The reason why the RMSE is relative high is due to the fact that data were collected during days with no rain. On rainy days the concentration of suspended sediments in the water was higher than 10000 mg/l. The RMSE for suspended solids ranged from 29.6 to 595 mg/L for the different subcatchments.

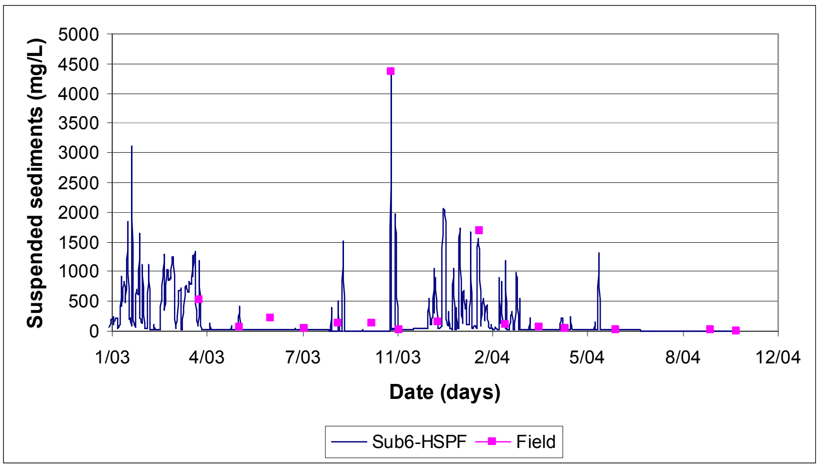

Figure 3. Suspended sediments simulation of Krathis river and comparison with field data.

Water Quality simulation: Figure 4 presents a comparison of the field data with the simulated nitrogen and phosphorous concentrations. The model captured the seasonal variability in concentrations of nutrients. The goodness-of-fit between the observed and simulated nitrate, nitrite, ammonia and phosphate concentrations were estimated using the RMSE statistic. In general, the simulation resulted in low and within acceptable limits of RMSE values. The RMSE for nitrate-N ranged from21 to 134 μg/L for the different subcatchments, for ammonia-N from 7 to 16 μg/L, for nitrite-N from 0.3 to 1 μg/L, and for phosphate-P from 4 to 48 μg/L.The total nitrogen export from the watershed was estimated to be 0.16 g/m^2-yr. The total phosphorous export from the watershed was estimated to be 0.006 g/m^2-yr. Higher export values for N were simulated for subbasin 3 (0.235 g/m^2-yr) due to intensive agriculture activities and subbasin 6 (0.712 g/m^2-yr) due to wastewater disposal site and the interspersed septic tanks, compared to subbasin 1 (0.062 g/m^2-yr) that the main landuse was forest. The phosphorous export was very low due to its retention by the soils.

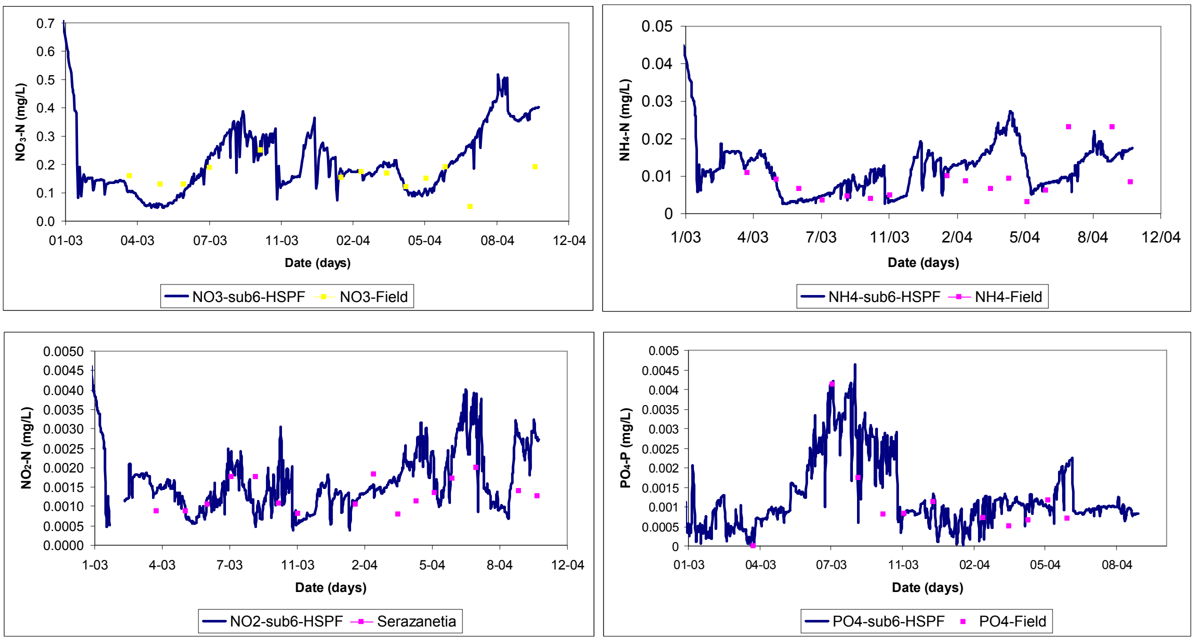

Figure 4. Nutrients concentration simulation of Krathis river and comparison with field data.

Relative high RMSE values were observed comparing field and model data. The main problem on that is that the monthly values that were obtained from the field were on days of no rain. Especially on rainy days or after the rain is observed an increase in the concentration of suspended sediments and a decrease in dissolved nutrients (Table 1). Also the observed values are simultaneous values and are compared with daily model values in order to estimate RMSE. However, the HSPF water quality simulation was adequate since the simulated fluxes were the same order of magnitude as the field data, indicating that the nitrogen and phosphorous cycle can be successfully simulated by the model.

TABLE 1. Suspended Sediments and Nutrients concentrations during the Rain Events and their average value

Rain Event	**Suspended sediment** (mg/L)	**NO_3-N** (mg/L)	**NO_2-N** (mg/L)	**NH_4-N** (mg/L)	**PO_4-P** (mg/L)
First Rain Event - 25/10/2003	1179.1	0.07	0.001	0.054	0.005
Second Rain Event- 31/10/2003	4359.8	0.08	0.002	-	0.005
Average Water Quality (April 2003-December 2004)	247.9	0.14	0.001	0.010	0.006

Climate Change Scenarios: The changes in temperature and precipitation were the output for the climate change model HADCM2 (**Had**ley Centre **C**oupled **M**odel v**2**.). HadCM2 has a spatial resolution of 2.5° x 3.75° (latitude by longitude) and the representation produces a grid box resolution of 96 x 73 grid cells. This produces a surface spatial resolution of about 417 km x 278 km reducing to 295 x 278 km at 45 degrees north and south. The atmospheric component of HadCM2 has 19 levels and the ocean component 20. The equilibrium climate sensitivity (DT2x) of HadCM2, that is the global-mean temperature response to a doubling of effective CO_2 concentration, is approximately 3.0°C [9]. The simulations of HSPF showed a decrease in river flow that was 0.7% for 2020 year, 0.71 % for 2050 and 1.85 % for the year 2080. Concerning the nitrogen cycle it was observed that the nitrogen output of the river will be decreased 8.34 % for the 2020, 9.12% for the 2050, 10.3% for the 2080 in relation to the simulation of 2003. Concerning the phosphorous cycle the model didn't result in any significant changes for the different climate change scenarios.

4. CONCLUSIONS

HSPF is a comprehensive, physically based hydrologic and geochemical model that has been applied to many watersheds in North America and Europe. It can simulate rivers, lakes, reservoirs and ground water. It has been recently modified to include irrigation and best management practices. The model has an adequate parameterization of sediment transport and comprehensive C, N, P cycles for the terrestrial and aquatic portions of the watershed. In addition, the model can simulate water quality constituents such as organic chemical and heavy metals through a generic parameterization. HSPF combined with the BASINS framework is a powerful tool for water quality assessments at the watershed scale.

The HSPF model is capable of simulating the hydrology of Krathis river successfully. The statistics of the performance of the hydrologic model were very good. The model performance was limited by the quality of the field data. Since it is a comprehensive model, it requires a substantial amount of field data that are not always available in Greece and mainly in an ungauged basin. The flow at the outlet for 2003 estimated to be 1391 m^3/d. The baseflow contribution was estimated to be 493.8 m^3/d (fraction 35.5 %) and the water from the land 897.2 m^3/d (fraction 64.5 %). Thus, 35.5 % of the river flow was simulated by the stochastic baseflow model and 64.5 % was simulated by HSPF.

The application of the HSPF model in Krathis river revealed several weaknesses that are inherent to watershed models and should be corrected in order to simulate properly Mediterranean temporary river watersheds. These weaknesses were:

1. **Problems in simulating heavily modified systems:** Most of the watershed in Greece are heavily modified by having cross-subcatchment transfers of water for irrigation or other purposes and controlled dam outflows. This makes the simulation of hydrology and geochemistry very difficult and in some cases impossible. This problem can be overcome by simulating section of the watershed separately. This is not a critical problem for small watershed such as Krathis River, but only for large watershed such as Acheloos River.

2. **Can not simulate carstic "base-flow" - spring contribution to surface runoff:** This problem was illustrated in the hydrologic simulation of Krathis river. It can be overcome by separating the hydrograph and modeling the carstic flow separately and then adding this flow into the model.

3. **Does not simulate river losses to ground water:** The lower portion of Krathis river before it enter the sea has low slopes. Field studies have shown that the river discharges to ground water. These losses can not be modeled because the model does not have such a parameterization. Further studies will identify the significance of these losses and whether they should be explicitly included in the model.

4. **Can not simulate river dry-wet, expansion-contraction dynamics:** The model parameterization does not take under account the processes of the expansion-contraction dynamics in a detailed fashion. The hydrology of the river is allowed to become dry and get re-wet, however, the processes are not being scale-up to account for the dry-wet sequence.

5. **First flush effect:** After the dry period comes the first rain in the most of the cases with high density that can be characterized as "hot moment". During the first flush and the following rain events the discharge, the sediments and particulate nutrients concentrations are extremely high comparing to baseflow conditions. Thus, it is very difficult to simulate the first flush effect and the high concentrations of the accumulated debris, the suspended solids and the dissolved nutrients that are transferred into the sea.

6. **Biogeochemical processes:** Incoming rain simulates pulses of biological and biogeochemical activity. Pulses are often short lived and the activity limited during extended dry periods. Most of the existing models include the nutrients processes in stream and in land but not in the riverbed. Even when the most part of the river bed area can be characterised as dry, the processes in that area appear high reactions rates during the extended dry period.

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