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Abstract: This paper describes the simulation of stream flow in ungauged watersheds using the computer model BISTRA (Basin Impacts of Simulated Transport from Rural Areas), developed by the Pennsylvania State University in collaboration with the Institute of Water Problems, Bulgarian Academy of Sciences. The main purpose of this GIS-based model is the quantification of diffuse pollution loads at the catchment level. To achieve this, BISTRA contains a sub-model for simulating hydrology in a catchment based on generic climate and landscape-related factors (e.g., daily precipitation and temperatures, soil, topography, land use, interdependence between surface and underground waters, etc.) which makes it possible to quantify monthly runoff, infiltration, and stream flow in areas where there are no gauge station records. The calibration and validation results for stream flow simulations conducted in the Yantra River basin in Bulgaria are given. The conclusion is made that after calibration and validation, the model can be applied to determine the runoff and stream flow at different points of the river network where there are no gauge stations.

***Keywords**: hydrology; stream flow; GIS hydrology models.*

1. INTRODUCTION

The development of river basin management plans requires availability of long-term stream flow data for the purpose of estimating water balances at different points in a stream network. This is oftentimes very difficult because the gauge stations (GSs) used for flow monitoring are either insufficient in number, or they are irregularly distributed in the catchments. Most GSs are typically situated in the middle and downstream portions of the catchment, which presents difficulties for evaluation of stream flow in the upper stream reaches. Also, the middle and down-stream portions of river basins are often highly-developed, and exhibit numerous anthropogenic activities such as water supply intakes, and dams and reservoirs. In such areas, the observed flow is often greatly disturbed, which creates serious difficulties for assessing stream flow in the larger basins via simulation. Consequently, the estimation of stream flow volumes in these cases based on the use of generic climate and landscape-related factors is a very useful and powerful procedure because it is possible:

- To assess stream flows of ungauged river basins;
- To evaluate the natural flows for long periods of time;
- To help in the choice of a gauge station analogue and to extend the hydrological records, and
- To make statistical assessments of stream flow volumes.

The BISTRA (Basin Impacts of Simulated Transport from Rural Areas) model was created as a result of collaboration between the Institute of Water Problems, Bulgarian Academy of Sciences and the Pennsylvania State University, USA, and is essentially an updated version of the GWLF (Generalized Watershed Loading Functions) model developed by Haith et al. [1992]. BISTRA includes an interface between GWLF and ArcView GIS software, and uses a number of GIS data layers (e.g., climatic conditions, land use and soil data, topography, etc.) to derive values for various GWLF model input parameters [Knight et al., 1999; 2001]. The BISTRA model has previously been applied in the evaluation of pollution loads in the Yantra River basin in Bulgaria [Hristov et al, 1999, Ioncheva et al, 1999]. Described in these papers are the calibration and validation results for stream flow simulations performed for this basin.

2. OVERVIEW OF THE BISTRA MODEL

The GWLF model contained within BISTRA is used primarily for assessment of non-point source (diffuse) pollution loads from agricultural lands, wash-off from urban lands, and septic systems in rural settlements. Surface runoff, a main transport mechanism of nutrient and sediment loads, is determined based on the use of generic factors related to landscape and climate. The basic components of the GWLF model on which BISTRA is based consist of:

- a surface runoff component (based on the Soil Conservation Service Curve Number model [SCS-CN approach; Haith et al., 1992];
- an erosion and sediment delivery model (based on a modified Universal Soil Loss Equation combined with Vanoni's watershed sediment delivery ratio function, based on watershed size [Haith et al., 1992]), and
- a nutrient production model (based on dissolved- and sediment-attached nutrients carried with runoff and sediment).

2.1. Input Data and Output Results for the BISTRA Model

Execution of the BISTRA model requires three input files (i.e., *weather.dat*, *transport.dat*, and *nutrient.dat*) which are prepared automatically via the ArcView GIS interface. Model parameter values are derived using information contained in a variety of GIS data layers, including the basin boundary (polygons), soil type (polygons), point sources (points), settlements (polygons), land use (grid theme), river network (lines), weather stations (points), topography (grid theme), and other customized data sets for the river basin (Knight et al., 2002). The *weather.dat* file includes information for daily precipitation and daily temperatures; the *transport.dat* file contains information for such things as land use characteristics, evapotranspiration coefficients, runoff curve numbers, soil data, universal soil lost equation (USLE) factors, groundwater recession coefficients, and other initial transport conditions; and the *nutrient.dat* file contains information related to source area loading rates and background concentrations of nutrients in soil and groundwater.

The output results are given in *summary.txt* and *monthly.txt* files, which contain monthly distributions of precipitation, evapotranspiration, ground water flow, surface runoff, stream flow, erosion, sediments, and dissolved and total nitrogen and phosphorus. Results are also presented by source area.

3. CALIBRATION OF BISTRA MODEL

Calibration of the BISTRA model was conducted on five sub-basins of the Yantra River basin for the period 1989-1995 (see Figures 1 and 2).

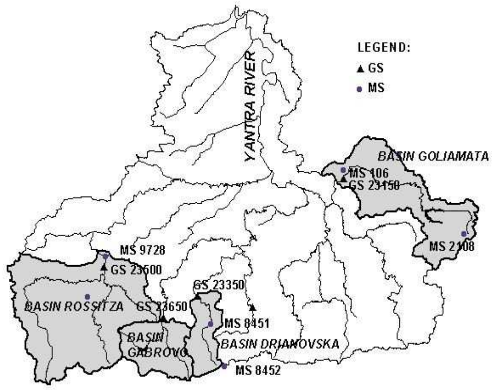

Figure 1. Location of the calibrated sub-basins.

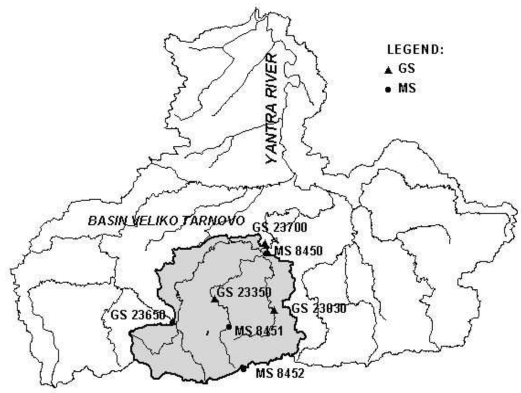

Figure 2. Location of Veliko Turnovo sub-basin.

These included the Drianovska sub-basin with gauge station (GS) 23350, the Yantra by Gabrovo sub-basin with GS 23650, the Rossitza sub-basin with GS 23500, the Yantra by Veliko Turnovo sub-basin with GS 23700, and the Goliamata sub-basin with GS 23150. The location of these sub-basins is presented in Figures 1 and 2. (Note that two of the smaller sub-basins – the Drianovska and Yantra by Gabrovo – are nested within the larger Yantra by Veliko Turnovo sub-basin).

These sub-basins were selected for the following primary reasons:

- The outlet of the sub-basin or group of sub-basins coincided with a GS for comparison of the simulated and observed flows;
- Stream flow was relatively unaffected by anthropogenic activities;
- The sub-basins are situated in different parts of the larger Yantra River basin;

- The sub-basins were mainly composed of agricultural or rural land use types;
- The sub-basins did not include significant point source discharges.

Based on a sensitivity analysis of the various model input parameters, it was determined that the most critical parameters were the groundwater recession (GWR) constant, the available water-holding capacity (AWC) parameter and the evapotranspiration (ET) cover coefficients. Consequently, adjustments to these parameters were primarily made during the calibration phase. The calibration results for the Veliko Turnovo sub-basin in which simulated stream flow is compared with observed stream flow is shown in Figure 3.

4. VALIDATION OF THE BISTRA MODEL

Validation is an obvious requirement since no model may be used in the practice without suitable proof of its capabilities for solving real problems. In this case, validation of the BISTRA model was performed on four additional sub-basins of the Yantra River basin for the same 1986-1995 time period. The locations of these sub-basins (the Yantra before Lefedja mouth sub-basin; the Yantra after Lefedja mouth sub-basin; the Yantra after Rossitza mouth sub-basin, and the Yantra by Karantzi sub-basin) are presented in Figure 4. The corresponding comparisons between the simulated and the observed flow, assessed on the basis of in-stream monitoring data for the upper basins, are presented on Figures 5 to 8.

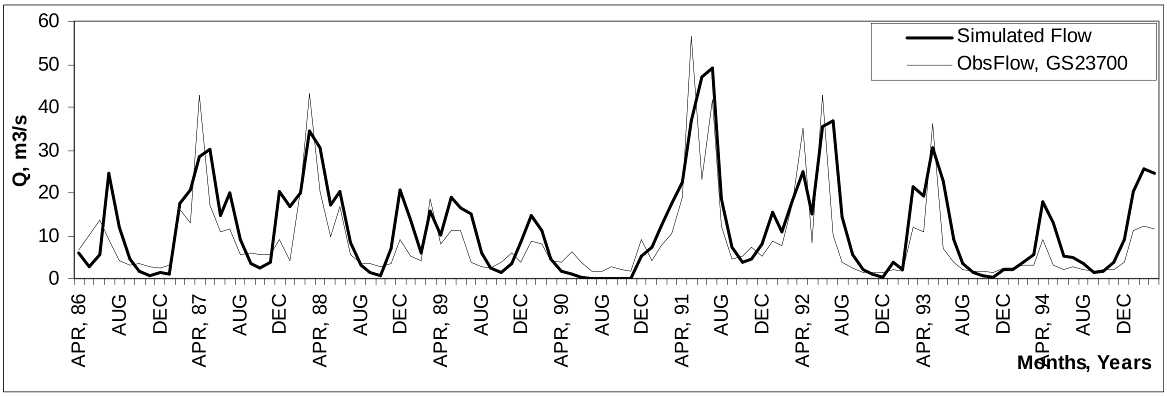

Figure 3. Calibration of BISTRA model for sub-basin Veliko Turnovo for the period 1986-1995

5. STATISTICAL ASSESSMENT

Hydrologic models are used most frequently to simulate or predict flows either on a continuous basis or for a particular event, and simulated (computer model) flow is typically compared with observed (measured) flow to assess model utility. In such cases, it is recommended that both visual and statistical comparison between model computed and measured flows be made whenever data are presented. The visual comparison is a necessary first step in the evaluation, and often takes the form of graphic plots of the simulated and the observed flows. This first step provides a general overview of the model performance and provides an overall feeling for model capabilities.

For the work presented in this paper, the statistical assessment involved the calculation of a number of statistical parameters. The values of the statistical parameters are given in Table 1. The values of calculated index of agreement ("d", as described by Willmott [1984]) show that the simulated flows developed using BISTRA model appear to compare very favourably with the measured flows for various sub-basins of the Yantra River watershed. In this case, the index of agreement (d) varies between 0.0 and 1.0, where a value of 1.0

Figure 4. Locations of the sub-basins for BISTRA model validation

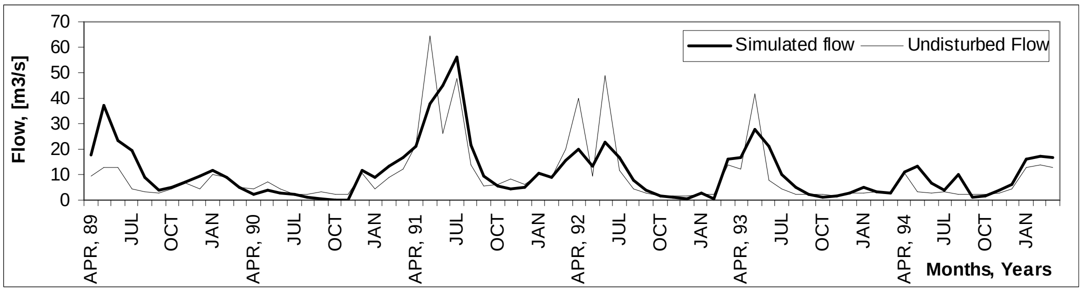

Figure 5. Validation of BISTRA model for sub-basin Yantra before river Lefedja for the period 1989-1995

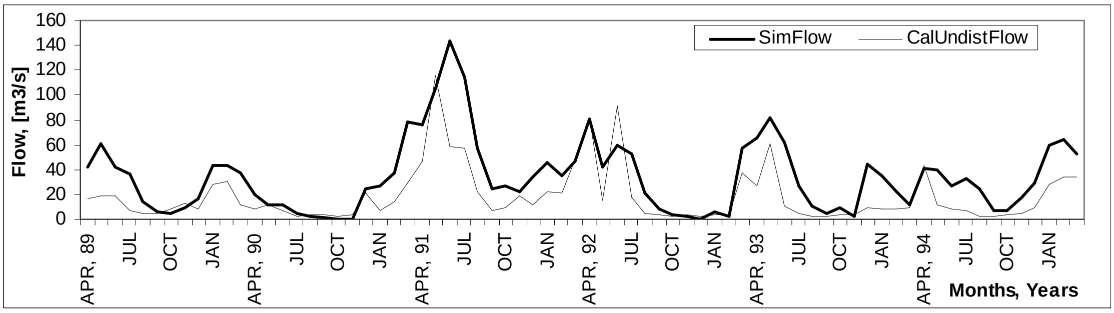

Figure 6. Validation of BISTRA model for sub-basin Yantra after Lefedja for the period 1989-1995

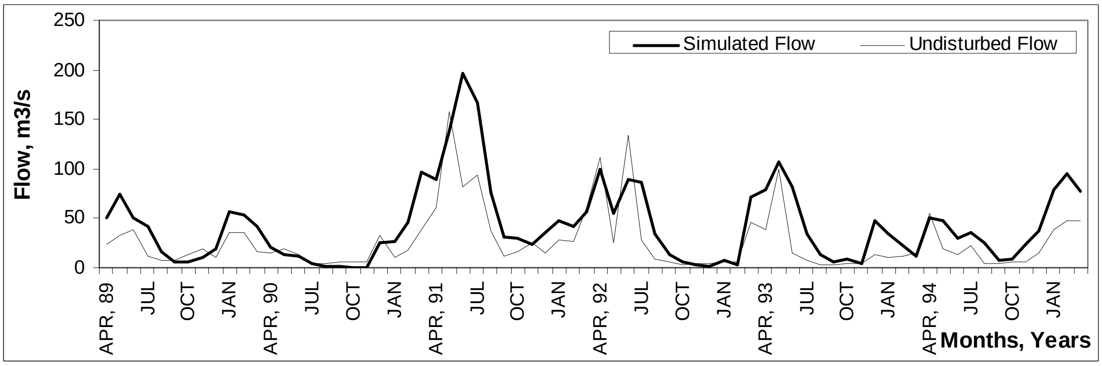

Figure 7. Validation of BISTRA model for sub-basin Yantra after river Rossitza for the period 1989-1995

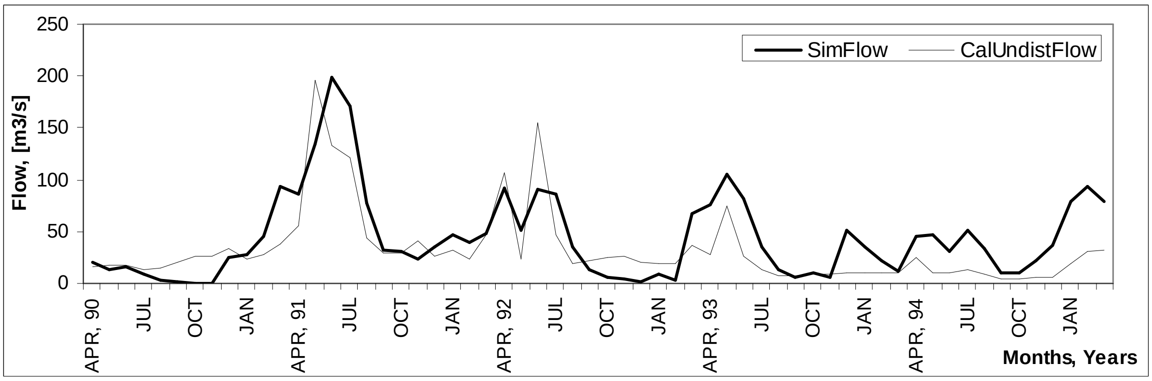

Figure 8. Validation of BISTRA model for basin Yantra by Karantzi for the period 1990-1995.

expresses perfect agreement between observed (O) and predicted (P) values, and 0.0 describes complete disagreement.

6. APPLICATION OF BISTRA MODEL IN THE PRACTICE

The BISTRA model was used to determine the stream flow for the period 1986-1995 of an ungauged sub-basin in the upper part of the Yantra River (the Elenska River), which was an area targeted for water management purposes. An additional study to assess the adequacy of the results was completed for the sub-basin Zlatarishka that includes the sub-basin Elenska (Figure 9). Again, the results were quite satisfactory as shown in Table 1 and Figure10.

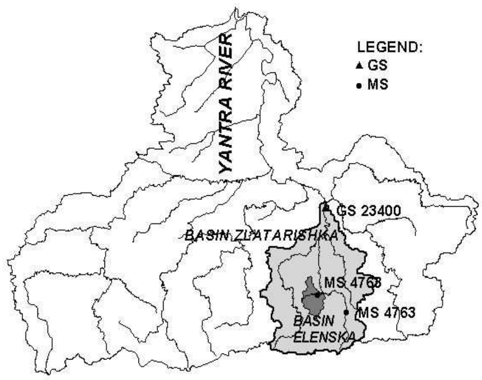

Figure 9. Location of sub-basins Zlatarishka and Elenska

Table 1. Statistical results

Basin	O*	P*	N	a	b
Veliko Turnovo	9.05	11.50	108	3.80	0.85
Zlatarishka	5.25	8.10	95	3.70	0.84
Yantra before Lefedja Mouth	9.58	12.64	72	5.35	0.76
Yantra after Lefedja Mouth	18.37	33.55	72	14.25	1.05
Yantra after Rossitza Mouth	26.84	42.30	72	14.63	1.03
Yantra by Karantzi	30.26	42.30	72	16.01	0.87
Basin	**MAE**	**RMSE**	**$RMSE_s$**	**$RMSE_u$**	**d**
Veliko Turnovo	2.45	7.16	2.89	6.55	**0.88**
Zlatarishka	2.86	5.88	3.06	5.02	**0.83**
Yantra before Lefedja Mouth	3.05	7.94	4.20	6.74	**0.88**
Yantra after Lefedja Mouth	15.17	23.40	15.22	17.78	**0.80**
Yantra after Rossitza Mouth	15.46	28.03	15.49	23.36	**0.84**
Yantra by Karantzi	12.04	29.10	12.84	26.12	**0.83**

Where: O*-mean monthly observed value; P*- mean monthly simulated value; N-number of cases; a, b-simple linear regression coefficients, associated with an ordinary least-squares (OLS) simple linear regression between O_i and P_i ; MAE-mean absolute error; RMSE-root mean square error; $RMSE_s$-average systematic portion of RMSE; $RMSE_u$-average unsystematic portion of RMSE; d-index of agreement;

**The terms N, b and d are dimensionless, the remaining measures have the units m^3/s (Willmott, 1984).

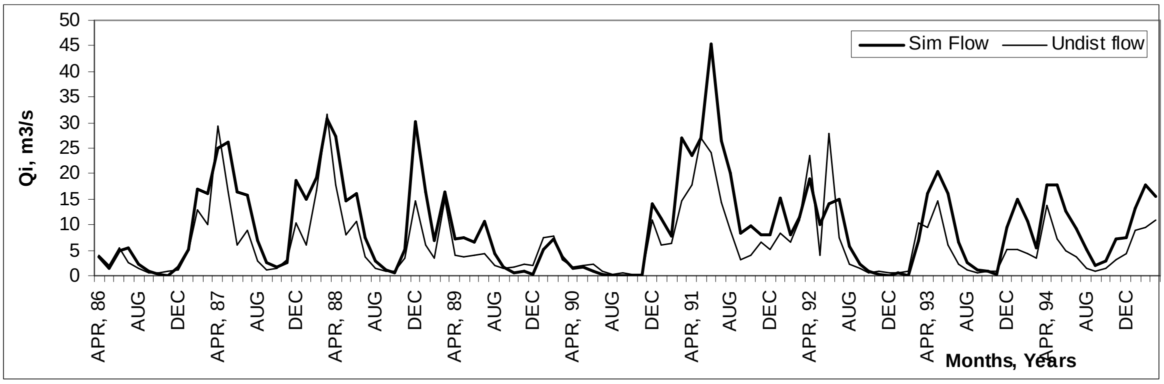

Figure 10. Comparison of simulated and undisturbed hydrographs of Zlatarishka catchment for the period 1986-1995

Conclusions

1. The investigation shows that the BISTRA model can be applied successfully to determine the stream flow at different points within a river network in which there are no gauge stations.
2. The simulation of stream flow, using the BISTRA model, has some advantages in comparison with the calculation of the stream flow on the basis of measured flow, which is often disturbed by ungauged water intakes.
3. The input data requirements for daily precipitation and temperature measurements are easier to obtain, and the required equipment for doing so is not as expensive in comparison with the monitoring of the steam flow by gauge stations.
4. The assessment of steam flow via a GIS-based approach as described above can provide the basis for a new hydrologic monitoring strategy. For example, the number of gauge stations could be reduced considerably, relegating their role and disposition in the watershed to the support of model calibration. At the same time, it might be reasonable to increase the number of weather stations in a given region to more accurately depict meteorologic conditions.

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