
CHARACTERISATION OF THE UPPER TELEAJEN RIVER BASIN USING MODEL-BASED INDICATORS TO IMPROVE WATER RESOURCES MANAGEMENT

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Abstract

Hydrological modeling of watershed represents a tool widely used to manage, assess and simulate water resources. The paper presents the use of model-based indicators as a pre-assessment tool for the characterization of the upper side of Teleajen River Basin, starting from Maneciu Dam to the confluence with Crasna River near Homoricu village. The main purpose of this scientific work, was to predict the effect of land utilization and watershed conditions on the water quality, sediments, and nutrient loads with sufficient accuracy on this ungauged section of the river basin. The Geographic Information System (GIS) interface created for SWAT, called ArcSWAT was used to develop the watershed model. The software package was used to delineate the basin and its sub-components, The data layers were combined to obtain the model database. The model parameters were analyzed, ranked and adjusted for hydrologic modeling purposes. ArcSWAT model was chosen due to its versatility in tracking the movement and transformation of several forms of nitrogen and phosphorous. This model embedded within the ArcGIS system was evaluated by statistically analyzing the predicted sediments, nutrient loadings and organic load from and within the Teleajen River upper section, a watershed that is significantly impacted by agricultural, animal breeding and forestry operations. Predicted sediments loading in the selected watershed indicated a significant sediment transport from the watershed. Nitrates tend to reach higher loads in the second part of the year in contrast with nitrites, which showed the maximum values in the February-April period.

Keywords: watershed, SWAT model, GIS, water quality, nutrient loads

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1. INTRODUCTION

The current knowledge of the water cycle is imperfect being subject to random and complex processes that are difficult to entirely measure or estimate. Moreover, the data for all rivers composing a catchment network are scattered or incomplete making difficult the evaluation of river flow information for resource and hazard management purposes. When the direct data is missing, the most reliable support to make hydrological predictions in the ungauged river basins is the use of models.

There are several published reviews of hydrological modeling however some aspects of the field are changing rapidly, for example new developments in distributed modelling, treatment of uncertainty, modelling ungauged

basins and non-stationarity. An updated review of modelling capabilities and limitations is found in (Pechlivanidis et al., 2011). The hydrological modelling calls for the handling of a vast quantity of data and parameters, which often comes from different sources and methodologies of measurement that corresponding to different spatial and temporal scales. Because of its advantages of data collection, storage, management, analysis, format-conversion, and display GIS is a very powerful and promising tool in water resource assessment and management (Cannata, 2006). Most water pollution models have a structure of input/output system. However these models do not assume explicit knowledge of pre-biochemical reaction, such as the explicit pre-reaction concentration. An internally descriptive model exploits the available

information on the phenomena determining the system's behaviors (Huang and Morimoto, 2004).

The parameters that determine the degree of pollution of a stream refers to dilution flow, transport capacity, dispersion and biodegradation of pollutants, and oxygen gain by re-aeration and photosynthesis. An adequate mathematical formulation for the assessment of pollutants' distribution in various sections of a river might be achieved only with simplifications of the transport and dispersion of pollutants mechanisms and of the physicochemical and biological interactions (Iordache and Dunea, 2012).

Water quality is influenced by the basin characteristics such as land utilization and geology, the seasonal influence, the river flow and the water chemical properties of the tributaries. Important factors in the surface water balance are rainfall and snowmelt having quantitative and qualitative influences mainly due to the surface transport of germs, suspensions, pesticides and fertilizers (Dunea and Iordache, 2011). The runoff may occur on the ground surface (surface flow), in the first thick soil layer (subsurface flow), in the deeper soil (groundwater flow), in the rivers (channel flow), through the lakes (lake), and through the artificial basins (dam) (Cannata, 2006).

Furthermore, surface waters change their composition in the downstream sections because of their use for various purposes (domestic, industrial, agricultural, etc.) in the upstream part.

In Romania, the assessment of surface water quality is based on the biological, hydro-morphological, and physicochemical monitoring of priority pollutants discharged in quantities that exceed the standard limits. According to the current regulations, five water quality classes are distinguished: I (good condition) to V (very poor).

The paper presents the use of model-based indicators as a pre-assessment tool for the characterization of the upper side of Teleajen River Basin. The analyzed section starts from the Măneciu Dam to the confluence with Crasna River near Homorâciu village. The

main purpose was to predict the effect of land utilization and watershed conditions on water quality, sediment, and nutrient loads with sufficient accuracy on this ungauged section of the river basin. Area presents interest because: the water quality belongs to the first category, the basin has plenty of tourist resources and is under the impact of human activities, being a dense populated region with more than 11000 inhabitants.

ArcSWAT model (Neitsch et al., 2005) was chosen due to its versatility in tracking the movement and transformation of several forms of nitrogen and phosphorous.

2. MATERIAL AND METHODS

2.1 Characterization of the area

Teleajen River basin has an area of 1656 km², a length of 122 km, and an altitude of 1760 m at springs, and 81 m where is discharging in Prahova River. The main tributaries of Teleajen River and their lengths are as follows: Crasna (22 km), Vărbilău (37 km) and Dâmbul (39 km), on the right side, and Telejenel (22 km), Drajna (25 km) and Bucovel (25 km), on the left side according with The Atlas of Water Cadaster from Romania (1992).

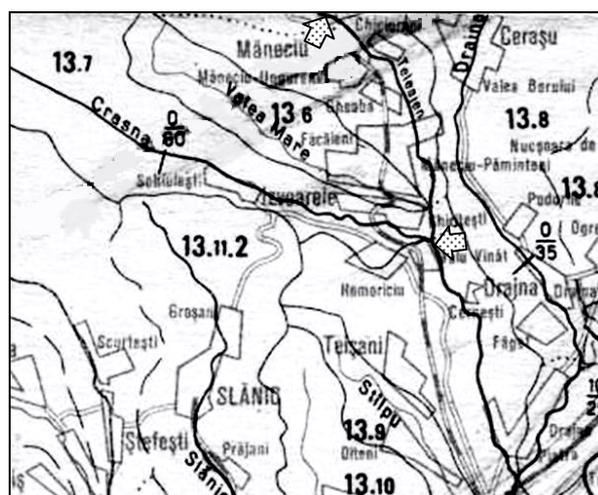


Figure 1: Hydrographical map showing the basins' delineation (13 – Teleajen River → 13.5 – Telejenel River; 13.6 - Valea Mare River; 13.7 – Crasna River) and the Teleajen River section considered for spatial analysis (see arrows)

In the Northern part of the basin, there are several water facilities that have impact on the water discharge parameters (Măneciu Dam) and on the water quality (3 water treatment plants: Cheia, Măneciu-Ungureni and Măneciu-Pământeni). The reservoir of Măneciu Dam has a surface of 382 ha, with a volume of 53.60 million of m³. There are 3 hydrometric stations that operate on the Teleajen river (Cheia, Gura Vitioarei and Moara Domnească) where daily observations upon the variation of the water level and periodically observations upon the water discharge and solid load, upon the dynamic of the river channel, as well as upon the physical, chemical and organoleptic properties of the water are made (Jipa and Mehedințeanu, 2012).

The Environmental Protection Agency of Prahova County has tested the concentrations in Cheia and Măneciu control sections of Teleajen River for organic load indicators, chemical indicators of water pollution (ammonium, phosphates and sulfates), and heavy metals (chromium, cadmium, iron and zinc) establishing that the water quality belongs to the first category. In the Gura Vitioarei section control, 55 km from Teleajen River spring, the water quality corresponds to the second category in accordance with the regulations regarding the surface water quality classification.

Figure 1 shows a portion of the hydrographical map [12] with the basins' delineation and the section of Teleajen River considered for spatial analysis (upstream outlet Stereo 70 coordinates: X -578119.923 m/ Y -425496.238 m, and downstream outlet: X -580272.649 m/ Y -419614.108 m).

2.2 Model description and configuration

Geospatial modelling of the selected river section was performed using ArcSWAT 2.3.4 for the ArcGIS 9.3 SP1 environment. SWAT (Soil & Water Assessment Tool) model was developed to predict the effect of alternative management decisions on water, sediment, and chemical yields with reasonable accuracy for ungauged rural basins (Neitsch et

al., 2005; Neitsch et al., 2004). The SWAT input and output interface tools were developed by Srinivasan R. (2010). Gasmann *et al.* (2007) published a review of an extensive range of studies that have been conducted with SWAT, highlighting the application trends together with a pertinent description of key strengths and weaknesses of the model.

Input information for each subbasin is grouped or organized into the following categories: climate; hydrologic response units (HRU); ponds/wetlands; groundwater; and the main channel (reach) draining the subbasin. Hydrologic response units are gathered land areas within the subbasin that are comprised of unique land cover, soil, and management combinations (Neitsch et al., 2005).

First step consisted in adding the required layers (Digital Terrain Model - DTM, land cover, soil map, and hydrography) and several optional layers (e.g. roads, localities, meteorological stations, gauge stations etc.). All layers were referenced to the same coordinate system using the stereographic projection (central meridian: 25, latitude of origin: 46 and the Scale Factor: 0.99975) and Dealul Piscului 1970 Geographic Coordinate System. The operation was done using the ArcCatalog, in the XY coordinate system tab of the *Shapefile properties* window.

DTM was developed from nine *.asc* files using the following ArcGIS procedure: create a new raster using *Create Raster Dataset* tool from the Data Management Tools in the Toolbox and setting it to 0, then *Mosaic* tool to add the required rasters to the newly created one with the *Blend* function. This command both added the Raster Data and merged the ASCII files together. The resulted DTM mosaic was geo-referenced and utilized for basin automatic delineation in the *Watershed delineator* module of ArcSWAT model for specific calculations such as: flow direction and accumulation, generation of stream network and outlets, watershed delineation and the calculation of the subbasin parameters. Nine outlets and nine subbasins were delimited by the model based on the DTM elevations (fig. 2). An elevation report for the watershed

was generated and consulted (min.: 434 m, max.: 1350 m and Mean elevation: 745.9 m, C.V.: 25.65%).

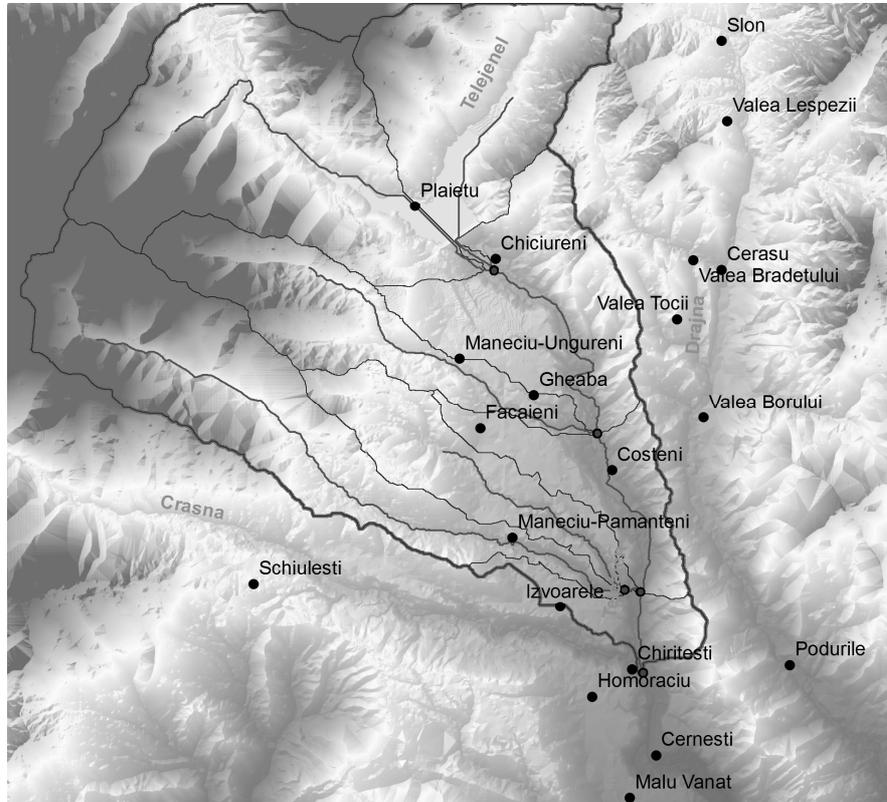


Figure 2: Digital Terrain Model and subbasins' delineation of the Teleajen River section watershed

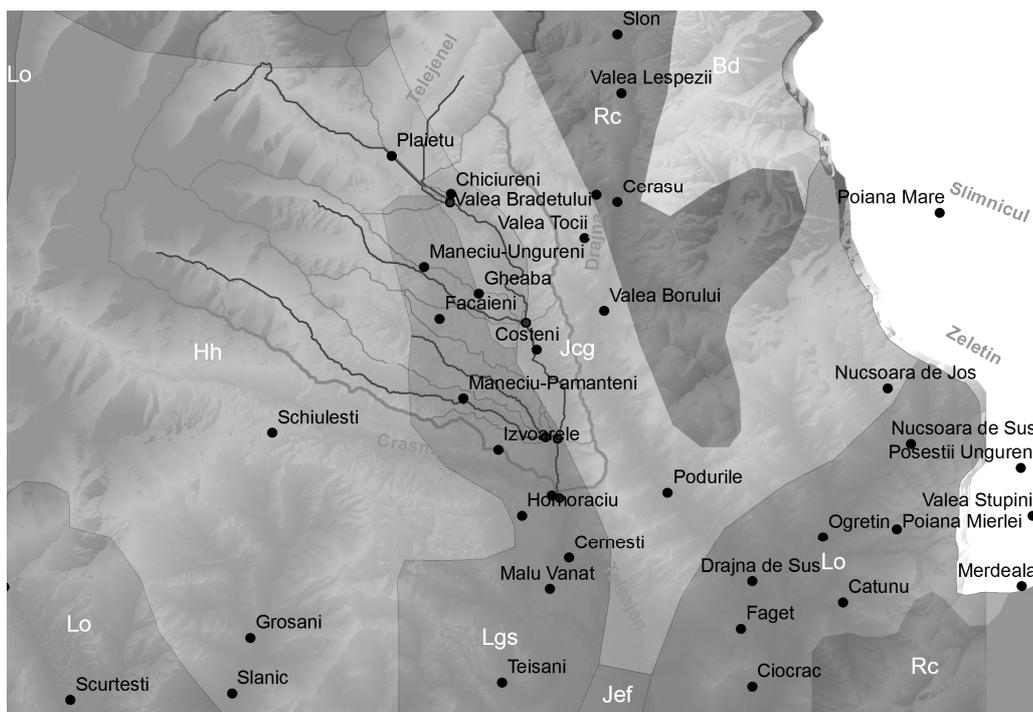


Figure 3: Soil map of the selected section of Teleajen River watershed



Figure 4: Land cover map of the selected section of the Teleajen River watershed

HRU analysis, which is the second module of the ArcSWAT, permitted the land use, soil and slope definition based on soil and land cover appropriate databases (fig. 3 and fig. 4). Two reports were generated: Land Use, Soils, Slope distribution and Final HRU distribution. There were identified 16 HRUs in the area. Climatic inputs used in the third module (*Weather stations*) of the model included daily precipitation, maximum and minimum temperature, solar radiation data, relative humidity, and wind speed data, which were inputted from measured records of 2011 year or generated.

ArcSWAT simulation was performed for one year (from 1.01.2011 to 31.12.2011) allowing a series of several physical processes to be assessed in the watershed on a monthly scale.

3. RESULTS AND DISCUSSION

Review of recent studies (Gassman et al., 2007) shows predominantly positive results for the SWAT model properly reproducing observed hydrological and water quality variables from the watersheds.

The SWAT model outputs various indicators such as sediments and water quality variables: total suspended solids (TSS), nitrogen species, phosphorous species, dissolved oxygen (DO), organic load, pesticides, and metals (Neitsch et al., 2004). In this paper, there are presented and statistically analyzed several important indicators for the 58 km² watershed section of Teleajen River, which have been simulated by ArcSWAT routine (table 1).

In the selected area of study, soil morphology is characterized by a great variety of terrain types in which medium and high hills are separated by deep valleys with torrential character increasing surface runoff. On the right side of the Teleajen valley, terraces are developed in the form of patches and stepped plateaus due to the height at which they are from the riverbed (50 m). On the left side there are steep versants and the hills. Higher terraces are cut and broken further by a series of perpendicular valleys on the flow direction of Teleajen (the valleys were formed by its tributaries).

3.1 Sediment (TSS) at the watershed outlet (SED_OUT)

Predicted Total Suspended Solids (TSS) loading in the selected watershed indicated a

significant sediment transport from the watershed (fig. 5 and table 1), since a significant portion of the watershed is covered by agricultural lands with thin brown alluvial soils that are susceptible to erosion.

Sediment transported with water out of reach during the monthly time step averaged 176.04 tons, which means a predicted daily load at the watershed outlet of approximately 0.5 tons. This value might match the size and conditions of the analyzed basin. Saleh *et al.* (Saleh and Du, 2004) found that the model efficiency of SWAT is higher in predicting monthly than daily TSS. In a similar basin, the measured TSS at outlet was 0.7 tons/day and SWAT prediction was 0.6.

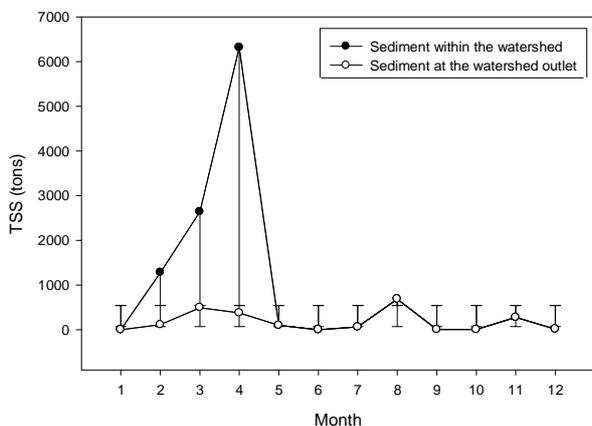


Figure 5: Simulated Sediment (TSS) in the destination reaches at selected downstream outlet and within the basin on a monthly scale (assimetric bars represents the corresponding standard error).

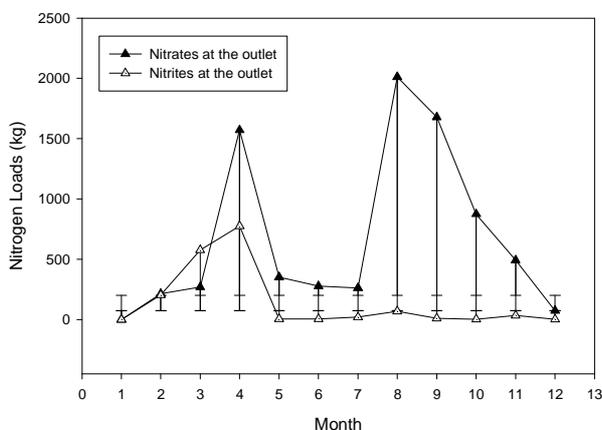


Figure 6: Simulated nitrates (NO₃-N) and nitrites (NO₂-N) out of the destination reach at selected downstream outlet on a monthly scale (assimetric bars represents the corresponding standard error).

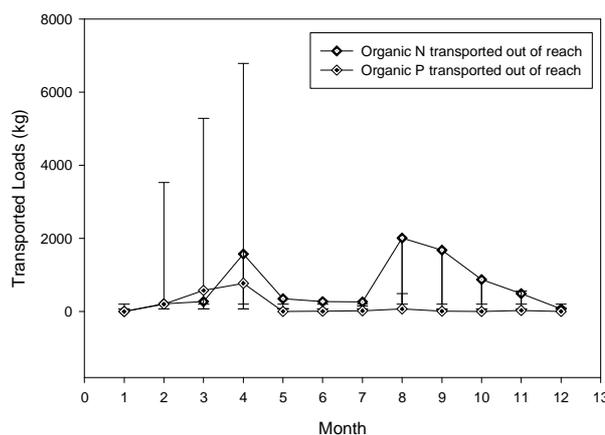


Figure 7: Simulated Organic nitrogen and Organic phosphorous transported with water out of reach on a monthly scale at selected downstream outlet (assimetric bars represents the corresponding standard error).

Table 1: Statistical indicators of the selected outputs resulted from the simulation on a monthly scale of the watershed conditions in the upper section of the Teleajen River

Variable	Average	Median	St.Dev.	Skewness	Kurtosis
SED_IN (tons)	947.34	78.04	1865.4	2.58	6.95
SED_OUT (tons)	176.04	78.04	229.9	1.30	0.67
SEDCONC (mg/kg)	9.24	5.99	9.1	0.31	-1.89
ORGN_OUT (kg)	1421.48	126.15	2388.1	1.62	1.27
ORGP_OUT (kg)	1706.23	19.05	3153.3	1.59	1.04
NO ₃ _OUT (kg)	673.10	314.10	693.8	1.08	-0.39
NO ₂ _OUT (kg)	142.01	14.77	259.02	1.99	2.91
MINP_OUT (kg)	257.34	14.04	464.9	1.79	2.01
CBOD_IN (kg)	2273.31	280.35	4304.8	2.43	5.99

Description of the variables (Neitsch et al., 2004)	
SED_IN (tons)	Sediment transported with water into reach during time step
SED_OUT (tons)	Sediment transported with water out of reach during time step
SEDCONC (mg/kg)	Concentration of sediment in reach during time step
ORGN_OUT (kg)	Organic nitrogen transported with water out of reach during time step
ORGP_OUT (kg)	Organic phosphorous transported with water out of reach during time step
NO ₃ _OUT (kg)	Nitrate transported with water out of reach during time step
NO ₂ _OUT (kg)	Nitrite transported with water out of reach during time step
MINP_OUT (kg)	Mineral phosphorous transported with water out of reach during time step
CBOD_IN (kg)	Carbonaceous Biochemical Oxygen Demand of material transported into reach (kg O ₂)

3.2 Sediment (TSS) within the watershed

Sediments transported with water into reach (SED_IN) were estimated at an annual average value of 974.34 tons, respectively 2.6 tons of sediments/day. These values are within the range of previous studies [3,10]. However, the simulated trend showed very high TSS loads from February to April. Excepting these months, the simulated SED_IN was almost identical with SED_OUT (fig. 5).

3.3 Nitrates and nitrites (NO₂_OUT; NO₃_OUT)

SWAT reasonably predicted nitrogen loss, computing the monthly average for nitrites and nitrates transported with water out of reach during the time step. On a monthly scale, simulation results for nitrogen loss showed consistency in previous studies (Gassman et al., 2007). Figure 6 shows different trends between nitrates and nitrites. Nitrates tend to reach higher loads in the second part of the year in contrast with nitrites, which showed the greatest values in the February-April period. Simulated daily nitrogen loss (both nitrates and nitrites) was estimated at 2.2 kg at the selected outlet of Teleajen River section.

3.4. Phosphorus loss (ORGP_OUT; MINP_OUT)

Phosphorus losses were also simulated with SWAT obtaining the organic phosphorous and the mineral phosphorous transported with water out of the river section. Figure 7 highlights the simulated evolution on a monthly scale. Table 1 presents an average annual load of 1706.23 kg for organic PO₄-P and 257.4 kg for the mineral PO₄-P.

3.5. Organic Load (CBOD_IN)

Carbonaceous Biochemical Oxygen Demand represents the quantity of oxygen required to decompose the organic matter transported in surface runoff (Neitsch et al., 2005). The simulated time series had an annual average of 2273.31 kg O₂ (table 1), which means a daily amount of approximately 6.2 kg O₂.

In order to explain some potential overestimations of the model, future work will

require a comparison of the sediment, nutrient and organic loads predicted by SWAT with the corresponding loads measured for this section of Teleajen River watershed, checking for consistency and calibration of the model.

4. CONCLUSIONS

A watershed SWAT model embedded within the ArcGIS system was evaluated by statistically analyzing the predicted sediment, nutrient loadings and organic load from and within the Teleajen River upper section, a watershed that is significantly impacted by agricultural, animal breeding and forestry operations.

Villages' development was done on the upper terrace, high and stable, but where flat surfaces were missing, villages continued to grow on the slopes of hills that descend to the Teleajen riverbed (Costeni and Chiciureni villages). Characteristic of this area are deep valleys and high hills with steep slopes, which are subject to constant erosion increasing the runoff processes.

From the statistically point of view, the outputs from the ArcSWAT model showed much dispersed time series with high coefficient of variations, and significant differences in terms of central tendency between average and median. All the distributions were right tail type considering the skewness values. Only two leptokurtic distributions were identified for SED_IN and CBOD_IN variables with higher peaks around the mean compared to normal distributions, which led to thick tails on both sides. Data are highly concentrated around the mean, due to lower variations within observations. All other variables had platykurtic distributions due to large variations within observations.

Future work will compare the predicted values against measured data from control sections for water quality and stream flow gauges within a larger scale watershed of Teleajen River basin. Likewise, the complexity will increase by adding the point source discharges existing within the area (3 WWTPs) and the reservoir (Măneciu Dam). It is expected that such improved digital model will

support decision making processes regarding the protection of water quality and efficient resources management in the Teleajen watershed.

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