# Modelling diffuse and point source pollution risks in the case of transboundary Sotla river basin

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## Abstract

The study was conducted on the river Sutla, which is a natural border between the Republic of Slovenia and the Republic of Croatia. This study aims to show the SWAT model results of diffuse and point source pollution risks in order to implement measures that could avoid a possible water quality deterioration, which is one of the biggest challenges in water management of this area. In the case of transboundary river basin, the challenge is even greater because of a range of factors related to diversity of water management, backgrounds, approaches, interests and development scenarios for the defined area. The performance indicators of the modelled daily flow (R2, NSE and PBIAS) during calibration period of 2009-2014 were 0.59, 0.61 and -10.58 and for the validation period were 0.54, 0.54 and 0.59, respectively. Monthly calibration objective function statistics NSE for sediment concentration, nitrate nitrogen load and mineral phosphorus load were defined as 0.72, 0.65 and 0.41, respectively. Results show that point sources in normal conditions contribute very small share of N (3.2%) and P (7.2%) on average daily basis.

**Keywords:** integrated water management, EU water policy, DPSIR, eutrophication, SWAT, good surface water status, measures





## 1 Introduction

For all river basins of the EU Member States water management must be organized in terms of implementation of the European water policy and objectives of the Water Framework Directive (WFD). Both Slovenia and Croatia, being the new EU Member States, are now faced with the great challenge to achieve not only the good ecological and chemical status of the Sutla Lake and the river Sutla (as directed by WFD), but also to achieve good or excellent quality for bathing and protection from adverse effects of water [3].

The implementation of the WFD is the starting point for the integrated water management. Small rural river basins, together with the lack of sanitation in agglomerations of less than 2000 ES and agricultural activities, present a challenge to water quality management for each state. These river basins are sources of organic pollution and nutrients, and the methodology to solve such problems is specific and dealt with at the national level, while the European water policy is conducted primarily in terms of achieving good status of all water bodies and environmental objectives for the river basin. In case of transboundary basins with high biological diversity and numerous NATURA 2000 areas, it is particularly necessary to apply an innovative approach to water quality management. Successful management of rural river basins includes various measures, from very expensive to low-cost measures to protect water bodies. Using appropriate mathematical models can help in the assessment of environmental impact and implementation of optimization measures. Through a preliminary selection of appropriate models for rural river basins, the mathematical model SWAT (Soil and Water Assessment Tool) was found to be appropriate [1]. SWAT also fits in the framework of integrated modeling, and thus allows the use of economic analysis and ecosystem services and human well-being [5].

## 2 Eutrophication assessment

European policy has consistently identified eutrophication as a priority issue for water protection, in particular through the Urban Wastewater Treatment Directive (UWWTD) and the Nitrates Directives (ND), as well as the more recent WFD adopted in 2000 and a number of international conventions on river basin management. Requirements to assess eutrophication are included in the EU water policy through some directives, as it is described in document „European assessment of eutrophication abatement measures across land-based sources, inland, coastal and marine waters“, ETC/ICM Technical Report – 2/2016“ [4]. There is no unique approach and relevant policy that aim at controlling the pressures from human activities with an impact on the natural condition of the ecosystem, status of water body and nutrient enrichment which cause eutrophication [4]. We present an innovative approach for the eutrophication assessment which is based on the:

- application of DPSIR approach to the analysis of human activities in the catchment area and the input of nutrients in the water with the use of spatial data (GIS);
- quantification of input pollution in water using a mathematical model SWAT:
- analysis of the condition of the water ecosystem in relation to the climatological-hydrological conditions, abiotic and biotic factors.





## 3 DPSIR and indicator system

With problem oriented DPSIR approach, according to the WFD, all types of pressures (pollution, water use and hydromorphological pressures) can be analyzed to asses the risk of not achieving a good ecological status of a water body [2].

The DPSIR framework distinguishes:

- driving forces (D),
- pressures (P),
- state (S),
- impact (I) and
- responses (R) - programmes and measures [4].

The eutrophication conceptual framework provides an effective mean for identifying the critical processes that can be adapted to processes specific to different water body categories. Using the indicator system, which explains causal relationship of the eutrophication process, special emphasis will be given on the analysis of biological indicators (elements of water quality) that are critical in the assessment of the state of aquatic ecosystems. Load indicators show how much nutrient loads have been reduced and whether the nutrient load reduction targets have been achieved. Nutrient emissions are assessed per sector and provide a direct link to the respective polluters. Data on sectoral nutrient emissions and the need for load reductions in each sector are gained by source apportionment. This is useful to identify the main contributors to the loads and where further measures would be most effective [4].

## 4 Material and methods

### 4.1 Study area

The river Sutla originates at the altitude of 717 meters below the Macelj hill and flows into the Sava River southeast of Brežice town. The terrain of the catchment area ranges from appr. 1000 meter above sea level to 100 meter above sea level (see Figure 2). It is 91 km long. After 3 km of headwater section, it becomes a national border between Slovenia (right side of the river) and Croatia (left side of the river). Its catchment area is 590.6 km² large, of which 78% is located in Slovenia, and the rest in Croatia. The average annual precipitation in the Sutla river catchment is 1200 mm, and evapotranspiration is about 650 mm. The river Sutla has the Pannonian flow regime with two identical peaks, one in early spring and the other in late autumn. Low flows occur in summer and winter. Measuring stations that monitor the quantity and quality of water on river Sutla (Figure 3) [1].

### 4.2 SWAT Model

The SWAT model, daily time step semi-distributed process-based catchment model, was developed to help water resource managers in evaluating the impact of agricultural activities on waters and diffuse pollution in river catchments [6, 7]. For the purpose of this study, SWAT 2012 model, Geographic Information System (GIS) ESRI ArcGIS 10.3 software and the ArcSWAT interface have been used.





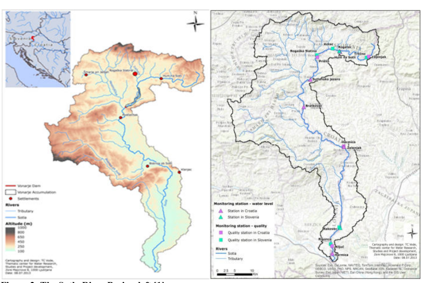

**Figure 2: The Sutla River Basin. -left [1]**
**Figure 3: Measuring stations that monitor the quantity and quality of water on river Sutla. – right [1]**

### 4.3 Database and data analysis

**Table 1: Model input data sources for the river Sutla sub-basin**

| Data Type | Characteristics | Source | Data description |
|---|---|---|---|
| Topography (DEM raster) | Slovenia: 25 m Austria: 1 m | Copernicus land services - European Environment Agency | Elevation |
| Soils | Slovenia: 1:25000 Croatia: 1:25000 | Ministry of Agriculture, Forestry and Food of the Republic of Slovenia; Biotechnical Faculty (University of Ljubljana), Faculty of Agriculture (University of Zagreb) | Spatial soil variability, soil types and properties |
| Land Use | Slovenia, Croatia: 1m vector data (Graphical Units of Agricultural Land) Croatia: 100 m Corine Land Cover (CLC) 2012, Version 18.5.1 | Slovenia: Ministry of Agriculture, Forestry and Food of the Republic of Slovenia Croatia: Paying Agency for Agriculture, Fisheries and Rural Development; Copernicus land services - European Environment Agency | Land use, Land cover classification and spatial representation |
| Land Management information | / | Chamber of Agriculture and Forestry of Slovenia - Agricultural advisory service; Field trip | Crop rotations (harvesting, planting, management), fertilizer application (rates and time) |
| Weather | Slovenia 9 and Croatia 3 stations | Environment Agency of the Republic of Slovenia (ARSO), Croatian Meteorological and hydrological service | Daily precipitation, Temperature (max., min.), relative humidity, wind, solar radiation from 2001 - 2014 |
| River discharge | 1 monitoring point (CRO - Zelenjak) | Environment Agency of the Republic of Slovenia; Hrvatske vode – Croatian legal entity for water management | Daily flow data (m³/s) from 2001 - 2014 |
| Waste water treatment plants | Slovenia: 10 Croatia: 2 | Environment Agency of the Republic of Slovenia; Hrvatske vode – Croatian legal entity for water management | Average daily discharge of orgP, sediment and orgN and other parameters |
| Water quality | 1 monitoring point (CRO - Zelenjak) | monthly monitoring | TSS, $NO_3^-$, $PO_4^{3-}$, TP, TN (2001 - 2012) |





### 4.4 Model set up and evaluation

The River Sutla catchment was subdivided into 11 sub-catchments and 1970 HRUs. The number of HRUs in each sub-catchment was set by a minimum threshold area of 0%:0%:0% for land use, soil and slope classes, respectively. High number of HRUs is correlated with step topography, dispersed agricultural areas and 39 soil types of the study area. River flow daily time step sensitivity analysis and calibration were performed for the sub-catchment 6 outlet for the period 2009-2014, with a three-year warm up period (2001-2003) and one validation periods (2004-2008). Sediment, nutrients (NO3-N, $PO_4^{2-}$) monthly time step and river flow daily time step sensitivity analyses and calibrations were performed for the water quality monitoring point at the sub-catchment 6 outlets for the period between 2004 and 2012. For the sensitivity analysis and calibration, special software called SWAT-CUP is used, and within it the Sequential Uncertainty Fitting (SUFI-2) algorithm [6,14].

## 5 Results

### 5.1 Calibration and Validation

Objective functions show that the simulated total flow is within the acceptable range (Table 3). To achieve acceptable calibration and validation results, a list of model parameters was changed from default to final values. Table 3 lists the calibration and validation values for the model performance for flow. Negative PBIAS values indicate a small overestimation of the simulated values. Nash-Sutcliffe efficiency ($E_{NS}$) on daily time steps are in the acceptable range [15], however, the $E_{NS}$ coefficient is very sensitive to values that stand out from the average [16]. The SWAT model simulated the streamflow trends good and very good, as simulated streamflow values do not exceed the measured streamflow data by more than 15% [15]. Comparing simulations run under different time steps shows that this element is important for understanding model performance [16]. After the base model calibration was completed, the parameters remained fixed for further use in scenario modelling. The results of the validation in this study are in line with the calibration results. Objective functions for monthly time step sediment, nitrate-nitrogen and phosphorus calibration (Table 3, Figure 4) show that the model is acceptable for predicting all of them. The Nash-Sutcliff coefficient ($E_{NS}$) is in the range of very good results for sediment, nitrate-nitrogen and satisfactory for phosphorus and PBIAS in the range of satisfactory model performance for sediment and very good for nitrate nitrogen and phosphorus [10].

**Table 3: Statistical values for the calibration of for river flow (m³/s) (2004 – 2014) and sediment concentration (mg/l), nitrate nitrogen concentration (mg/l) and load (kg/day) and mineral phosphorus load in the river Sutla (2004 – 2012)**

| | Objective function | |
|---|---|---|
| | $E_{NS}$ | PBIAS |
| **River flow (daily)** | | |
| Calibration (2009 – 2014) | 0.59 | -10.58 |
| Validation (2004 – 2008) | 0.54 | 0.59 |
| **Sediment (monthly)** | | |
| Load Calibration (2004 – 2012) | 0.72 | 34.35 |
| **Nitrate nitrogen (monthly)** | | |
| Concentration Calibration (2004 – 2012) | 0.82 | -1.96 |
| Load Calibration (2004 – 2012) | 0.65 | 31.30 |
| **Mineral phosphorus (monthly)** | | |
| Load Calibration (2004 – 2012) | 0.41 | 2.32 |





### 5.2 Base scenario results

Through analysis of the base scenario, the critical source areas (CSAs), i.e. where the source and transport areas that are connected to water bodies, have been determined. HRUs where the annual average sediment yield exceeded 0.5 t/ha and average nitrate nitrogen loading from groundwater exceeds 5 kg/ha are considered to be CSAs (Figure 4). The average annual sediment and nitrogen yields at the HRU level were divided into six classes (Figure 4). The source of sediment in this river basin is spatially heterogeneous and on average 0.76 t/ha/year. This study shows that in certain HRUs, sediment yield can reach up to 31.61 t/ha/year (Table 7, Figure 4). This value can be exceeded during periods of heavy rainfall. The highest amount of sediment is transported from vineyards (3.5 t/ha/year), followed by arable fields (186 t/ha/year) (Figure 5).

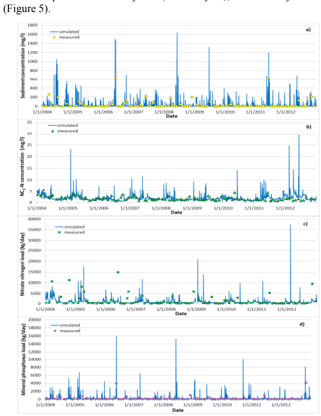


**Figure 4: A comparison of the simulated and the calculated sediment load (a), nitrate-nitrogen concentration (b) and load (c) and phosphorus load (d) in the river Sutla for station Zelenjak at subbasin 6 outlet between 2004 and 2012**





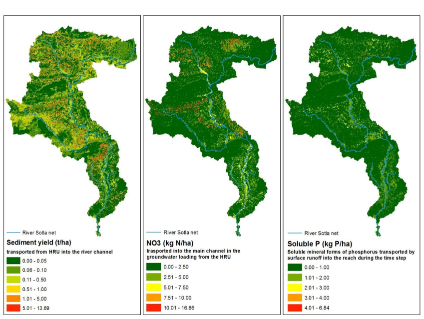


**Figure 5: Average annual sediment yield (t/ha/yr) and nitrate-nitrogen yield (kg N/ha/yr) transported into the main channel from the HRU.**

The areas with arable fields and especially the one on shallower soils and on lowland sandy soils are exposed to nitrogen and phosphorus leaching which ends in the main river channel. Their sources in groundwater in this river basin are spatially concentrated on agricultural land and are on average 1.97 kg N/ha/year and 0.59 kg P/ha/yr. This study shows that in certain HRUs, nitrate nitrogen and soluble phosphorus yield can reach up to 54.53 kg/ha/year and 12.99 kg/ha/year, respectively (Figure 5). This value can be exceeded during periods of heavy rainfall. The highest amount of nitrate nitrogen is on average transported from orchards (4.5 kg/ha/year), amount of soluble phosphorus in mineral forms is on average transported into the main channel from arable fields (1.7 kg/ha/year), followed by orchards (0.8 kg/ha/year) and vineyards (0.7 kg/ha/year). Modelling results for the study period between 2004 and 2014 also showed that on average it can be expected at the main catchment outlet at confluence with the river Sava almost **14.000 tons/year of sediment, 1741 tons/year of total nitrogen and 125 tons/year of total phosphorus.** Results show that main point sources (waste water treatment plants) in normal conditions contribute very small quantities of N (10.75 tons/year) (0.62%) and P (4.29 tons/year) tons of (3.43%) on average daily basis.





### 5.3 Results of indicies analysis for biological water quality elements, algae as eutrophication indicators

Analyzing the SWAT model results and the available water quality data based on the surveillance monitoring, which is carried out by Croatian Waters, as well as the results of the investigative monitoring, an analysis of the indexes for the biological elements of water quality and the presence of algae as an indicator of eutrophication was made. The Trophic Diatom Index (TDI) is a parameter that points to the load of the water body on the nutrients and the water temperature, i.e. its level of trophies based on the presence of diatom species (algae) [17]. The saprobic index (saprobity) (SI) is a multimeter index that indicates the amount of nutrients in the watercourse. SI [18, 19] was calculated according to the revised saprobic values for each diatom species (algae) according to the Croatian HRIS (Croatian Saprobic Index) indicator system [20]. The non-Diatom index (NDI) gives information on the presence and percentage of all groups of algae (except diatoms) in a single sample. Namely, the presence of Cyanobacteria and Chlorophyta may significantly imply an increase in the level of trophy / saprobity. Because of this biological quality assessment only on Diatom index can be questionable, especially at degraded sites. For the classification of the biological state it is important to define Ecological Quality Ratio (EQR). Namely, the values of each index used differ significantly and it was necessary to transform these values into comparable form, i.e. the actual values of the index are transformed into values between 0 and 1 (0 is highest quality and 1 is the worst).The EQR values for the TDI and SI index for the Sutla-Prišlin sampling station for 2012 (Figure 3), when regular monitoring was conducted by Croatian Waters, were 0,38, which indicated poor water status, while values for $SI_{PB}$ and $SI_{HRIS}$ were 0.74, indicating the good water status. EQR values for the TDI and SI index for the Sutla-Zelenjak sampling station for 2012 (Figure 3), when regular monitoring was conducted, were 0.69, which indicates good water status, as values for $SI_{PB}$ and $SI_{HRIS}$, which amounted to 0.77 and also indicated on the good water status. The EQR values for the TDI and SI index for the Sutla-Harmica sampling station for 2012 (Figure 3), when regular monitoring was conducted were 0.68, which indicates good water status and values for SIPB and SIHRIS were 0.75 and also indicated on the good water status. EQR values for NDI for all three sampling stations were 0.3 and indicated poor water status.

### 5.5 Measures

The planning and implementation of measures for reducing the risk of eutrophication has to be based on respecting the interests of all users of the river basin, and if is it possible, the ecosystem service and human well-being. The program of measures to reduce nutrient pollution pressures is the central element of an integrated water resources management plan that ideally fulfils the requirements of different water related policies like WFD, UWWTD, ND and national legislation [4]. Nutrients are a key factor in eutrophication and should be included in monitoring programmes for the assessment of eutrophication. Basically, two different monitoring concepts can be applied: monitoring of biological quality element(s) including supporting quality elements and monitoring of nutrients (and possibly other physico-chemical quality elements) as a screening tool. Generally, monitoring of nutrients will be at a higher frequency than for biological quality elements. [4]. In the case of Sutla River monitoring of biological quality elements is not sufficiently developed according to the requirements of the WFD. The analysis of total nitrogen and total phosphorus is the basis for budget calculations and overall assessments have been done by using the model SWAT. By using additional extensions for the model, this budget can be improved. For a detailed analysis of eutrophication processes all fractions of nutrients (dissolved and particulate, organic and inorganic forms of nitrogen and phosphorus) should be monitored to allow a better understanding of the status and the factors explaining the status. Such a detailed analysis can be part of an investigative monitoring programme, as it in case of Sutla catchment area [4]. The programme of measures may be established when the most significant pressures have been identified and nutrient reduction objectives have been set. While the WFD, ND and MSFD give more space for the selection of specific and site adapted measures, the UWWTD defines clear technical and managerial measures to be taken. Mandatory measures, according to UWWTD, have been implemented for aglomerations bigger than 2000 p.e, but waste water in other settlements is collected in individual permeable septic tanks if not emitted directly into small creeks and rivers. Out of a total of 54,839 residents living in the Sutla river basin, only 11070 inhabitants are connected to the sewage system and WWTP. The EU-WFD planning process distinguishes three categories of measures: basic measures, supplementary measures and additional measures. The program of measures has to be cost-effective and consulted with stakeholders to become operational and includes better cross-sectoral integration of water policiesburden sharing between sectors, innovative approachment, and alternative concepts such as payment for ecosystem services.





## 7 Conclusion

An innovative methodology for eutrophication assesment using the DPSIR approach with GIS spatial analysis and the SWAT model is presented in the paper. The application of this methodology has proven to be appropriate on Sutla river basin case study because it enables the analysis of the eutrophication process in the basin as well as the selection of the optimal set of mitigation measures for prevention of the eutrophication process. Further and widespread application of this approach will enable wider acquisition of the basic knowledge for the Sutla river basin, which includes the natural processes, the generating pollution and decreasing risk of eutrophication. All input data that are used were provided by the official monitoring system, but it is necessary to continue the collection of new data and further development of the SWAT model for which it has been proven that it can improve the quality of the analyzes, especially by using different extensions. In the future, it is necessary to carry out more detailed research of biological elements of water quality, especially perifiton and macrophytic vegetation, which are directly related to eutrophication. Research should take place for at least three consecutive years in the warmer part of the year during lower water levels in order to obtain a complete picture of the state of Sutla Lake.

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