MODELLING ACTIVITIES FOR COMPREHENSIVE WATER AND NUTRIENT BALANCES FOR TWO AUSTRIAN CASE STUDY REGIONS

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ABSTRACT

To analyse the causative processes of anthropogenic nutrient emissions and to improve the water protection management in the Danube river basin and the Black Sea, the daNUbs-project (Nutrient Management in the Danube basin and its impact on the Black Sea) was established. The main emphasis is on diffuse pollution and the transport, retention and losses of nutrients such as N, P and Si in rivers and lakes. In Austria, two case study regions were selected representing contrasting climatic, hydrological and ecological conditions. Water balance calculations and hydrograph separation techniques were applied using three models, SWAT 2000, DIFGA 2000 and MONERIS. The model results were then compared in terms of comparability, reliability and the potential of identifying the main pathways of nutrients in the catchments. The SWAT 2000 model was used to identify the differences in the hydrologic dynamics of the two catchments. The components of the water cycle were estimated with an emphasis on evapotranspiration, runoff generation and the relative contribution of the runoff components. The results indicate that the two catchments differ significantly in their nutrient release and hence their potential contribution to eutrophication of the Danube river basin. The DIFGA 2000 model was used for hydrograph separation analyses and for assistance in the calibration of the SWAT 2000 model. The MONERIS model, an empirical, GIS-based model for large river basins, was applied to address scale- and basin-related problems associated with analyses covering the whole Danube basin. The semi-distributed modelling of the water balance taking into account different landuse, soil and geological conditions facilitated the assessment of the vulnerability of the catchments in terms of nutrient emissions or instream loads. A comparison of the model results showed that the different model types provided different model capabilities. The disadvantages also differ as a result of differences in the model parameter definition, model uncertainty, model complexity, general applicability and physical significance. The models were found to be complementary in terms of their merits and deficiencies, so a joint application of all three models was found to be likely advantageous.

Keywords: daNUbs, Danube, catchment hydrology, water balance, watershed modelling, nutrient balances, Eutrophication

INTRODUCTION

During the last decades, anthropogenic nutrient emissions have caused severe ecological problems, especially deterioration of groundwater conditions and eutrophication of rivers, lakes and especially the receiving seas. It is of decisive importance to analyse the causative processes and to improve the water protection management on catchment scale. These problems have a big scale dimension. The daNUbs-project "Nutrient Management in the Danube Basin and its impact on the Black Sea" (EVK1-CT-2000-00051) is performed within the 5th EU Framework Directive. It aims to investigate the interaction between Danube Basin and Black Sea, where nevertheless the connections between manmade activities as nutrient management and the resulting water pollution on regional scale in order to improve approaches for big scale application will be studied. Six different case study areas to perform comprehensive nutrient balances have been selected, located in Austria, Hungary, Romania and Bulgaria. Schilling et al. (2002) and Strauss et al. (2002) provide more background information about the daNUbs-project workplan and activities in the different case study areas are published. In Austria, two rivers were selected as case study regions representing contrasting climatic, hydrological and ecological conditions.

The location of the two case study regions is shown in Figure 1. The elevation distribution in the Ybbs catchment, with a range from 250m to 1900m above sea and an average slope of 31%, differs significantly from the elevation distribution in the Wulka catchment, with a range from 125m to 750m above sea level and an average slope of 8%. The landcover of the Ybbs catchment is dominated by forest, following grassland or pasture and arable land. The Wulka catchment is mainly covered by arable land, following forested areas and grassland or pasture (see Figure 2).

As a main basis for the estimation of nutrient balances, which it is intended to do in detail for both catchments, water balance calculation were performed using two different models and a hydrograph separation technique. The main emphasis was to point out differences in the behaviour of both catchments with regard to the relative contribution of the runoff components, i.e. surface runoff, interflow and baseflow caused by differences in climatical conditions (amount of precipitation, ETR), landuse characteristics, soil structures or hydro-geological formations.

MODEL APPLICATION

Water balance calculations and hydrograph separation techniques were applied using three models, the SWAT 2000 model, the DIFGA 2000 model and the MONERIS model.

The **SWAT 2000** model (Arnold, et al., 1999) is a spatially distributed, conceptual model for continuous modelling continuous time model. The SWAT 2000 model is able to simulate the hydrologic cycle on the basin level and allows a number of different physical processes in a catchment to be simulated. Additionally, the model is able to simulate nutrient and pesticide routing and transformation in the catchment and inside the river. Because of its physical nature there is a large demand of data needed to specify input parameters of the model. In the SWAT 2000 model, three runoff components will be used for comparison with results fro m DIFGA and MONERIS, i.e. the Surface Runoff (**SURQ**) the Lateral Flow (**LATQ**) and the Baseflow (**GWQ**).

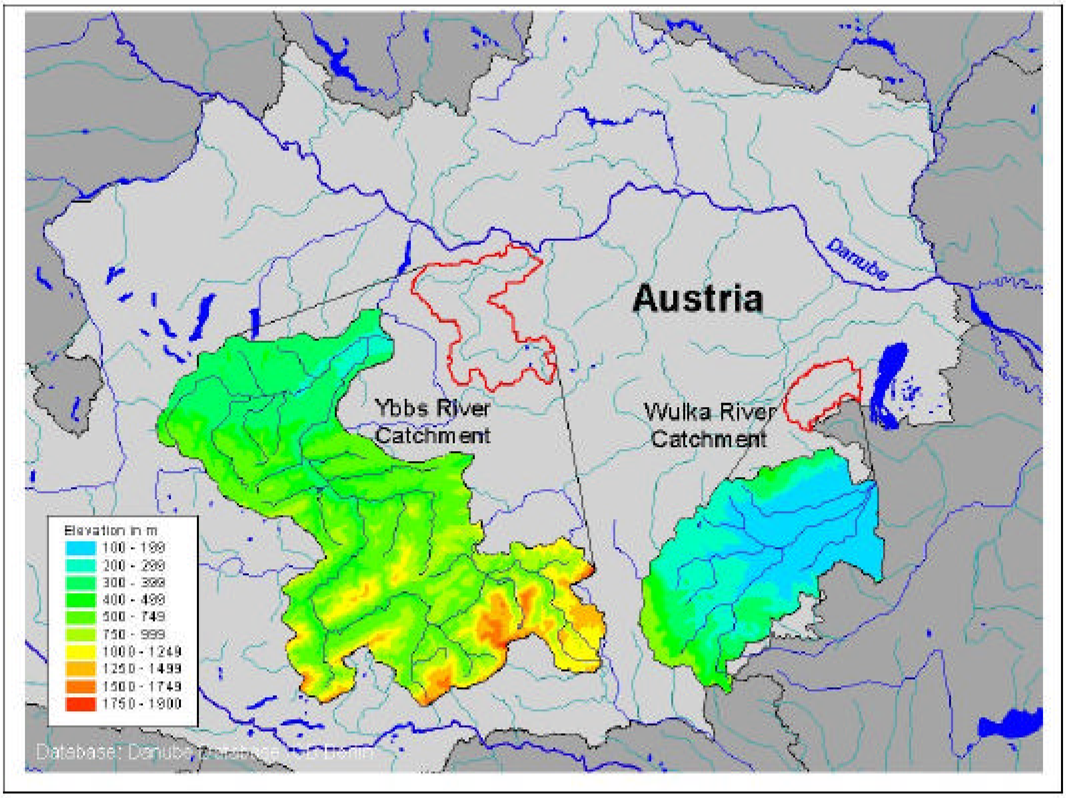

Figure 1: Location and elevation distribution of the selected case study regions in Austria

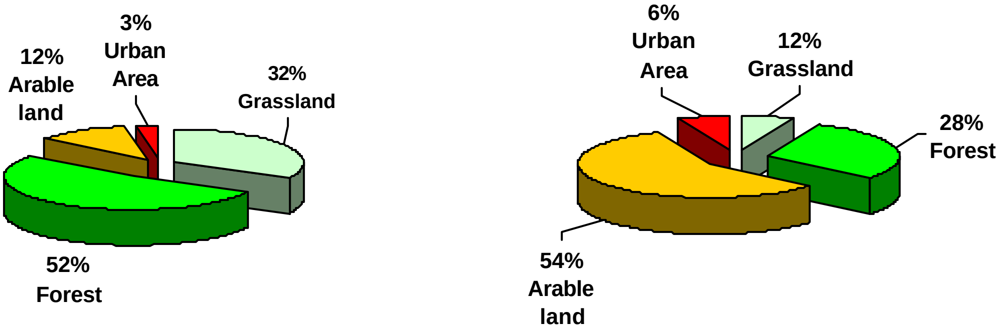

Figure 2: Landuse characteristics in the Ybbs catchment (left) and the Wulka catchment (right)

The **MONERIS** model **(MO**delling **N**utrient **E**missions in **RI**ver **S**ystems) (Behrendt and Bachor 1998) was developed and applied to estimate the nutrient inputs into river basins of Germany from point sources and various diffuse pathways. The model is based on data of river flow and water quality as well as a geographical information system (GIS), which includes digital maps and extensive statistical information. Consequently seven pathways of emissions into the rivers are considered (Point sources, Atmospheric deposition, Erosion, Surface runoff, Groundwater, Tile drainage, Paved urban areas). MONERIS estimates the different pathways with already existing and new conceptual approaches, which are developed especially for the modelling in the medium and large spatial scale. In the MONERIS model, the components Groundwater flow (**Q_{GW}**), Overland flow (**Q_{RO}**), Direct precipitation (**Q_{AD}**), Tile Drainage (**Q_{DR}**), Point sources (**Q_{PS}**) are considered in the Water balance calculation are used for comparison with SWAT 2000 and DIFGA.

The DIFGA 2000 model/software package (Schwarze, 2000) was used for hydrograph separation. It has two linear storages for groundwater, and uses a lithofacies-concept to separate the runoff into three components, the direct runoff (**QD**), a fast (**QG1**) and a slow (**QG2**) groundwater component. It tries to find recession parameters for the two groundwater storages depending on hydro-geological and morphological characteristics of the catchment.

The runoff components of the three different models are compared in Table 1.

	SWAT	***Moneris***	***DIFGA***
River discharge	WY	Q	Q
Point sources	PS	Q_{PS}	-
Baseflow	GWQ	Q_{GW}	QG1+QG2
Lateral flow (Interflow)	LATQ		
Surface runoff	SURQ	Q_{RO} + Q_{URB} (+ Q_{AD})	QD
Drainage runoff	TILEQ	Q_{DR}	

Table 1: Comparison of the runoff components of the SWAT 2000 model, the MONERIS model and the DIFGA 2000 model

MODEL CALIBRATION

The calibration of the SWAT 2000 model was dedicated to refine model parameters in order to get an optimal fitting of the model in terms of regional hydrological and climatical conditions. The calibration was performed comparing the simulated runoff against the observed runoff. As calibration criterion the Nash&Sutcliffe coefficient (Nash and Sutcliffe, 1970) was used. Additionally, an automatic calibration tool (van Griensven 2002), which was applied for the ESWAT model, could be applied for the SWAT 2000 model. This tool uses the Shuffled Complex Evolution Algorithm (SCE-UA) (Duan et al., 1992) for optimisation, where several objective functions are aggregated to a Global Optimisation Criterion, that has to be minimised. After applying the SCE-UA-Algorithm for every subcatchment, the parameter set with the best model efficiency was selected.
On basis of the distribution of the runoff components coming from the DIFGA model, the calibration of the SWAT model was carried out. In that way, the relative contribution of the components Surface runoff, Lateral Flow and Groundwater Flow of the SWAT model was set equal to the relative contribution of the components Direct Runoff, fast Groundwater Flow and slow Groundwater Flow from the DIFGA.

This way of calibration was successful for the Ybbs catchment only. In the Wulka catchment, the influence of drainages and inlets from wastewater treatment plants (30% contribution to the total river runoff) seemed to be too high to be well considered by both models, the DIFGA 2000 model and the SWAT 2000 model. Analysis of the calibration results indicates, that the SWAT 2000 model was well capable to reproduce low flow conditions (Baseflow). Surface runoff events caused by high precipitation events, leading to high flow conditions, have been modelled in a quite acceptable way. Concerning the mean flow conditions, there is still a need for adjustments of the SWAT model.

For the MONERIS model, all the necessary input data were determined using GIS-maps or statistics provided by local and governmental agencies and authorities. A calibration of the model was not necessary.

For the DIFGA 2000 model, a calibration was not performed. Necessary model input definitions had to be made by definition of the litho-facies types and by an adjustment of the regression line which is fitted by the model.

WATER BALANCE ESTIMATIONS

Due to the data availability and the data needed to define the model input, the simulation period of the water balance varies for the three models. For the SWAT 2000 model, data about the climatical conditions and the hydrology (precipitation, air temperature, wind speed, relative humidity, wind speed, river discharge) are needed to specify the parameter input. The interval with the highest availability of data for the SWAT 2000 model were the years 1992-1997. The MONERIS model uses 5-years-averages to specify the model input. Due to the interval of the statistic data and the comparison with water quality data were obtained during the last two years, the optimal interval was found to be1997-2002. The DIFGA 2000 model only needs river discharge data to specify the model input. Therefore, we used the complete runoff time series, with data from the period1971-1997. All water balance components were calculated as long-term average annual values. The results for the water balance estimations of the two Austrian case study regions are displayed in Table 2.

Table 2: Results of the water balance calculations for the Ybbs catchment and the Wulka catchment using the SWAT 2000 model, the MONERIS model and the DIFGA 2000 model

		Ybbs			Wulka		
Catchment size	[km²]	1117			384		
Average Precipitation	[mm/a]	1377			708		
Average river discharge	[m³/s]	32.7			1.23		
Average river discharge	[mm]	923			101		
Evapotranspiration	(SWAT)	376			576		
		SWAT [%]	***Moneris [%]***	***DIFGA [%]***	***SWAT [%]***	***Moneris [%]***	***DIFGA [%]***
Point sources		1	1	1	26	29	30
Baseflow		45	91	70	40	59	55
Lateral flow (Interflow)		35			10		
Surface runoff		19	8	29	5	4	15
Drainage runoff		-	0		19	8	

Note: For the SWAT 2000 model, the relative values of the runoff components are referenced to the simulated river discharge.

Significant differences between the two Austrian catchments can be seen, first in the exposition to precipitation (the average annual precipitation amount of the Ybbs catchment is twice as high as the average annual precipitation amount of the Wulka catchment), and second in the amount of the evapotranspiration (despite the lower precipitation amount, the evapotranspiration is 1,5 times higher in the Wulka catchment). That means, that in the Wulka catchment only less than 15% of the annual precipitation is contributing to the river runoff. In the Ybbs catchment, nearly 65% of the annual precipitation is contributing to the river runoff.

The relative contribution of the runoff components between the both catchments differ between the models too. A comparison of the relative contribution of the runoff components is shown in Table 2. Due to the different definitions of the runoff components used in the models, the bars sometimes compare on component from one model with the sum of two components from another model.

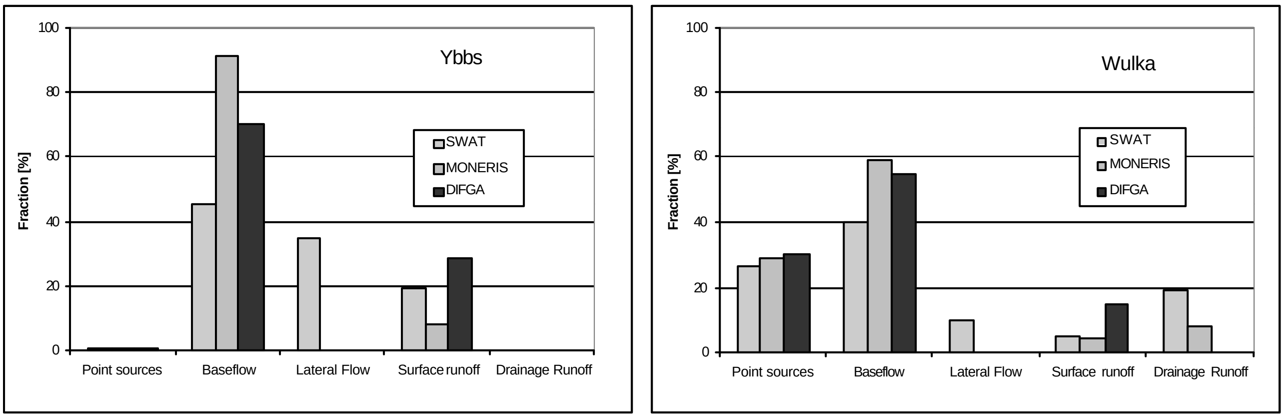

Figure 3: Differences in the relative contribution of the runoff components between the models for the two different catchments. (Left) The Ybbs catchment (Right) The Wulka catchment

The runoff components Baseflow and Lateral Flow of SWAT and DIFGA are nearly as high as the components in MONERIS and DIFGA in the Wulka catchment. In the Ybbs catchment, the MONERIS model calculates a higher contribution of the Baseflow and Lateral Flow than SWAT and DIFGA.

The estimated surface flow is much smaller with MONERIS than with the other models.

The comparison of the relative contribution of the runoff components Surface Runoff, Lateral Flow and Baseflow between SWAT and DIFGA showed a good match (due to the calibration assistance of the DIFGA model). For the Ybbs catchment, the Surface runoff calculated with DIFGA is higher than the Surface runoff calculated with SWAT. For the Wulka catchment, the relative contribution of the Surface runoff of the SWAT and DIFGA model is oppositional inverted.

The influence of Point sources and runoff from drained areas is obviously of a big importance in the Wulka catchment. The differences in the relative contribution of these two runoff components between the models are explainable with the ability of consideration in the model definitions (tile drainage) and the reference (point sources) to the simulated (SWAT) or measured (DIFGA/MONERIS) river discharges.

Generally, the main runoff component of the MONERIS model was the Baseflow. The DIFGA model showed a similar proportion of the relative contribution of the runoff components Baseflow and Surface runoff. In the SWAT model the Baseflow-component had the highest relative contribution followed by the components Lateral Flow and Surface runoff.

ESTIMATION OF NUTRIENT BALANCES

The calculation of catchment-wide nutrient balances rely very much on accurate water balances. The presented calculations of the water balances were aimed to quantify the different pathways of nutrient emissions from the catchments and the immissions into the streams. Point sources as inlets from wastewater treatment plants can be quantified more easily than the contribution from diffuse sources. The SWAT 2000 model is able to simulate the nutrient cycle and nutrient transport on the basin level and inside the streams. Degradation processes in the groundwater are not considered. The separation of the runoff into the three runoff components surface runoff, interflow and baseflow gives the possibility to quantify different sources of diffuse pollution spatially distributed and time-dependent over the catchment. The MONERIS model is able to quantify the nutrient emissions out of calculated nutrient surpluses and to quantify the nutrient loads to the streams on basis of empirical equations.

In Figure 4, preliminary results of the calculations of the total nutrient emissions of both catchments, the Ybbs catchment and the Wulka catchment are shown. In the Ybbs catchment, due to the high contribution of the Baseflow (see Fig. 3) the emissions from Groundwater is the most dominant part of the Nitrogen emission. Phosphorus is mostly emitted by erosion. In the Wulka catchment, the Nitrogen emissions by groundwater are also the most dominant part, but Nitrogen emissions from drained areas and wastewater treatment plants (WWTP) are also important. The most important Phosphorus emissions in the Wulka catchment are caused by erosion and WWTPs, but the emission from urban areas is also significant.

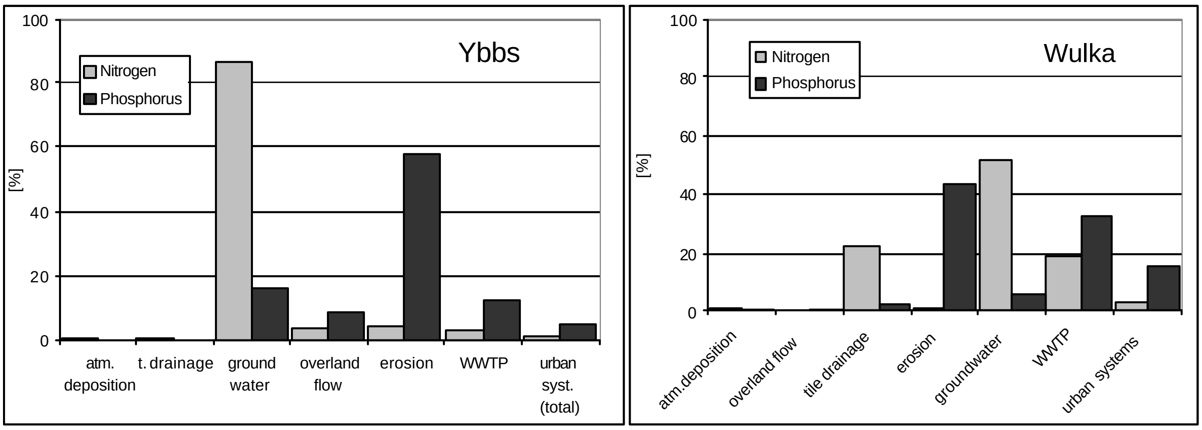

Figure 4: Total nutrient loads calculated with the MONERIS model for the Ybbs catchment (left) and the Wulka catchment

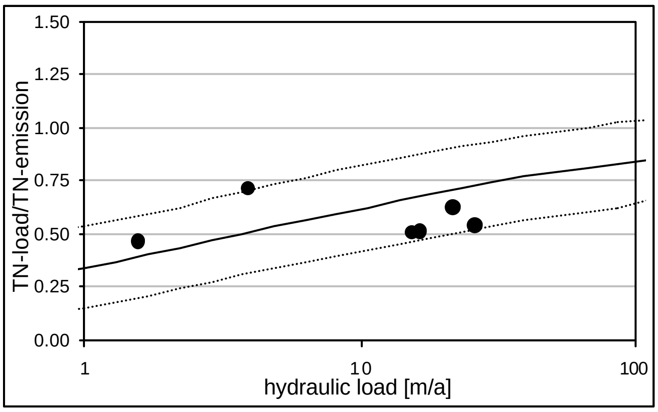

Figure 5: Comparison of the calculated and the measured hydraulic load of Nitrogen using the MONERIS model for the Ybbs catchment. The measured values are shown with points, while the straight line shows the results from the MONERIS model.

In Figure 5, for six river gauging stations in the Ybbs catchment the retention of Nitrogen in the stream was calculated and compared to the hydraulic load. This Figure shows the relation between the total Nitrogen emission that were calculated with MONERIS for the Ybbs catchment and the total Nitrogen concentrations that were measured at the river gauging stations. This empirical assumption for the in-stream Nitrogen retention was determined at several European rivers. The in-stream retention is dependent on the hydraulic load, which means the retentions decrease with an increasing hydraulic load. This Figure illustrates that the empirical assumptions made for large river basins also are applicable at smaller river basins like the Ybbs catchment.

CONCLUSIONS

Water balance calculations were done for two Austrian case study regions using the SWAT 2000 model, a distributed time continuous model of a physical nature, the MONERIS model, which is based on empirical equations and the software package DIFGA 2000 as a hydrograph separation technique.

The DIFGA 2000 model gave the most reliable results in terms of separation of total runoff into different runoff components, i.e. Direct runoff, slow and fast Groundwater runoff. The relative contributions of the runoff components were comparable in both catchments. The results from the DIFGA 2000 model were also used as assistance for the calibration of the SWAT 2000 model. Due to its physical nature, the SWAT 2000 model consists of various model parameter and the calibration was conditionally successful. For both catchments, the Ybbs catchment and the Wulka catchment, a detailed water balance with the main focus on the runoff components Surface runoff, Lateral flow and Baseflow and their relative contribution was calculated using the SWAT 2000 model. The MONERIS model was successfully applied for both catchments too. The high amount of the groundwater runoff is mainly caused by the definition as the difference of the measured total river discharge between two river gauging stations and all the other, empirically calculated runoff components. In spite of its development for large river basins the application of the MONERIS model for both catchments, the Ybbs catchment and the Wulka catchment, provided reliable results of Nutrient emissions, which are comparable to measurements taken in both catchment.

The model results showed that the different model types provided different model capabilities properties. The disadvantages? also differ as a result of differences in the model parameter definition, model uncertainty, model complexity, general applicability and physical significance. The models were found to be complementary in terms of their merits and deficiencies. Using the results of the MONERIS model there is a possibility to join the applications with, for instance, the SWAT 2000 model and to compensate lacks in processes are not considered well in one of the models. Further modelling investigations using the SWAT 2000 model for the calculation of spatially distributed nutrient balances will be performed and presented.

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