2

Strengths, Weaknesses, Opportunities and Threats of Catchment Modelling with Soil and Water Assessment Tool (SWAT) Model

Matjaž Glavan and Marina Pintar
University of Ljubljana, Biotechnical Faculty, Department of Agronomy, Chair for Agrometeorology, Agricultural Land Management, Economics and Rural Development, Slovenia

1. Introduction

Changed water regime in watercourses and high loads of sediment as a product of surface flow soil erosion can cause reductions in biodiversity, which is becoming one of the main indicators of environmental quality. Especially in the light of the European Union Water Framework Directive (WFD) (2000/60/EC) which requires new approaches, methods and tools for improvement, protection and prevention of further decreasing water quality. The main aim of the WFD is to achieve good quality status of water bodies in Europe by 2015 (Volk et al., 2009). Changes in social system and climate may, regardless environmental legislation restrictions, lead to changes in land use and hence in quantity of water flow and sediment concentrations in waters. Merging the different spatial and environmental data is time consuming; therefore, the use of computer modelling tools is necessary.

Models for catchments modelling can be divided into empirical-statistical (GLEAMS, MONERIS, N-LES), physical (WEPP, SA) and conceptual (distributed or semi-distributed - SWAT, NL-CAT, TRK, EveNFlow, NOPOLU, REALTA) (Kronvang et al., 2009; Hejzlar et al., 2009). Distributed and semi-distributed models have the best features for catchment modelling, as they can divide catchments into several smaller subcatchments and hydrological response units (HRUs) with its unique properties. This allows you to explore the responses of the catchments at different spatial and temporal dimensions. In contrast to the distributed models, semi-distributed models have limitation in simulating sediment and chemicals transport processes between HRUs. Generally have catchment models gained new value after they were placed in the geographical information system (GIS) environment. With the use of different cartographic databases it became easier to work with and spatially oriented results are more understandable to different target groups.

It is often claimed that models with diffused sources of pollution are not designed to simulate individual events but are primarily designed to assess long-term average values (Garen & Moore, 2005, Arnold et al., 1998). Current models for simulating water quality from diffuse sources have a lot of uncertainty in the projections (Garen & Moore, 2005) due to the influence of the study areas - heterogeneity, imperfect algorithms and scarce monitoring network. Modellers, regulators and policy makers must keep limitations of the models in their mind while they evaluate the results of the model simulations.

The Soil and Water Assessment Tool (SWAT) model was developed to help water resource managers in evaluating the impact of agricultural activities on waters and diffuse pollution in medium and large river catchments. The core of the model was developed on the basis of 30 years of experiences with modelling, as a continuation of Department of Agriculture of the United States of America (USDA) Agricultural Research Service (ARS) work (Gassman et al., 2007). The SWAT model is continuous-time, semi-distributed, process based catchment model, which was developed by merging three existing models - CREAMS, EPIC and GLEAMS (Gassman et al, 2007).

The model is extensively used in the world for modelling hydrology, water quality and climatic change (Krysanova & Arnold, 2008, Gassman et al., 2007). Applications of the model in the European Union (EU) were driven by Water Framework Directive enforced in 2000, which encourage the use of tools for assessment of diffused pollution, such as SWAT model (Barlund et al., 2007; Gassman et al., 2007). European Commission, for the purposes of ensuring adequate tools for the end-user that could satisfy the European need for harmonization of quantitative estimates of chemical losses from diffuse sources, has facilitated enforcement of the Water Framework Directive and the Nitrates Directive, funded EUROHARP project (Kronvang et al., 2009a, Kronvang et al., 2009b).

According to the Special Report on Emissions Scenarios (SRES) of the Intergovernmental Panel on Climate Change (IPCC) greenhouse gas emissions on a global scale is expected to increase the temperatures by 2100 (°C) for six SRES scenarios B1: 1.8 (1.1- 2.9), B2: 4.2 (1.4-3.8), A1T: 2.4 (1.4-3.8), A1B: 2.8 (1.7-4.4), A2: 3.4 (2.0-5.4) and A1FI: 4.0 (2.4-6.4) (Meehl et al ., 2005; Knutti et al., 2008). The possibility of realization of all scenarios in the future is equally probable, as they are based on different assumptions about the probable socio-economic development in the future. There is no doubt that air temperature will rise, however reliability of precipitation projections is lower, although there prevails a negative trend in the changes. Modelling of the IPCC scenarios have shown their impact on the catchments hydrology, on the infrastructure, on accumulation of carbon, on nutrient availability and plant growth (Sardans & Penuelas, 2004; Purkey et al., 2007).

General circulation models (GCM) well describe the process at a global level, but it is less reliable at the regional scale, since they do not include regional surface details. Therefore, the direct application of the results of GCM simulations in local and regional climate change negatively impact studies on agriculture, forestry, energy and water management (Bergant & Kajfež Bogataj, 2004). To bridge the gap between global and regional scale it is essential to couple GCM with nested regional model and provide potentially consistent geographical and physical estimates of regional climate change. To present local climate change features further empirical downscaling and various mathematical models are needed (Bergant & Kajfež Bogataj, 2005). However, projections of future climate changes, particularly at the local level, are accompanied by a number of uncertainties, which must be included in the analysis at the time of interpretation (Bergant & Kajfež Bogataj, 2004).

The aim of this chapter is to present strengths, weaknesses, opportunities and threats of the catchment model, Soil and Water Assessment Tool (SWAT), through two case studies catchments in Slovenia (Dragonja in Istria and Reka in Goriška Brda area).

2. Materials and methods

2.1 Study areas characteristics

The river Reka catchment spreads over 30 km² and is located in the north-western part of the Slovenia in Goriška Brda region (Fig. 1). Altitude ranges between 75 m and 789 m above sea level (a.s.l.). Very steep ridges of numerous hills, which are directed towards the southwest, characterizes the area. The catchment landscape is agricultural with large percentages of forest (56 %) and vineyards (23 %).

The river Dragonja catchment spreads over 100 km² and is located in far south-west of the Slovenia in Istria region (Fig. 1). This is a coastal catchment (Adriatic Sea), with an altitude ranging between 0 and 487 m above sea level (a.s.l). The ridges of the hills are designed as a plateau with flat tops and steep slopes. The landscape is largely overgrown with forest (63 %) and grassland (18 %). Terracing is typical for both areas and depends on natural conditions, steepness of the slopes (erosion), geological structure (sliding) and climatic conditions (rainfall).

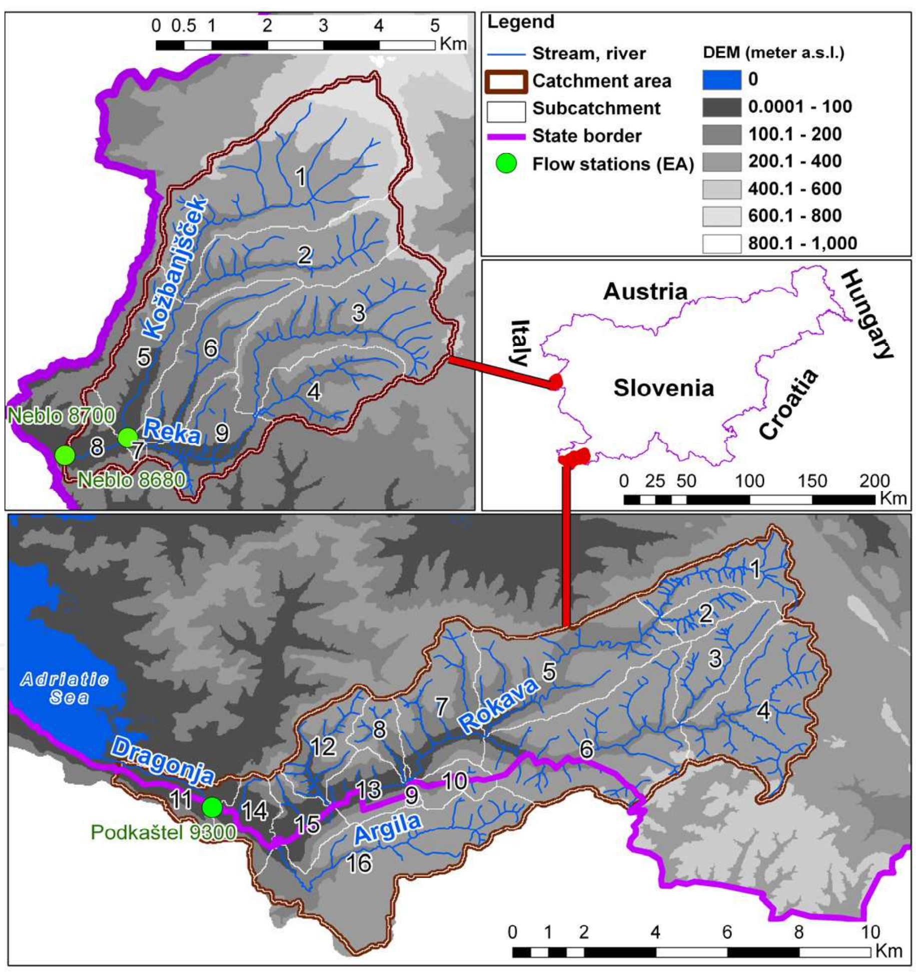


Fig. 1. The river Reka and Dragonja catchment case areas divided in sub-catchments

The bedrock of the study areas is Eocene flysch which consists of repeated sedimentary layers of sandstone and claystone. Soils are shallow brown euthric with silt-loam-clay texture that is difficult for tillage. With appropriate agro-technical measures (deep ploughing, organic fertilisers) they obtain properties for vine or olive production. In case of inappropriate agricultural activities and land management, we can witness very strong erosion processes.

Both areas are characterized by sub-Mediterranean climate (N Mediterranean – Adriatic Sea) with south-western winds and warm and moist air. Average annual temperature at the station Bilje (the Reka catchment), for the period 1991–2009, was 13.3 °C, and average annual rainfall in the period 1992 – 2008, was 1397 mm. Average annual temperature at Portorož station (the Dragonja catchment), for the period 1991 – 2009, was 14.1 °C, and average annual rainfall in the period 1993 – 2008, was 930 mm.

River network of the two areas is very extensive. Rivers are torrential and mediterranean. The average annual flow (1993-2008) of the rivers Reka and Dragonja is 0.59 m^3 s^{-1} and 0.87 m^3 s^{-1}, respectively, respectively, however summers have dry periods.

The annual average concentration of sediment in Reka catchment for year July 2008 – June 2009 was 32.60 mg l^{-1} (365 samples). In the river Dragonja catchment, the average annual concentration of sediment was 29.10 mg l^{-1} (107 samples) in August 1989 – December 2008. In January 2007, the highest sediment concentration of 1362 mg l^{-1} was measured. Data shows that sediment concentrations are wellin excess as compared with Environment Agency guide level (25 mg l^{-1}).

2.2 Database development for the model build

Field tour to the research areas and review of available data was carried out before the modelling started (Table 1). Since the available data was insufficient for modelling, we performed additional monitoring of sediment at the Reka tributary Kožbanjšček. Soil data was gathered from digital soil map and additional excavation of soil profiles and laboratory measurements were done. Using established model standards curve number (CN), albedo and organic carbon values were calculated. For water-physical soil properties (hydraulic conductivity, water-retention properties etc) pedotransfer functions were used (Saxton et al., 1986; Neisch et al., 2005; Pedosphere, 2009). For the purpose of this study we used the SWAT 2005 model, Geographic Information System (GIS) 9.1 software and ArcSWAT interface. Extensions necessary for SWAT functioning in GIS environment are Spatial Analyst, Project Manager and SWAT Watershed Delineator, which enables visualisation of the results.

SWAT is capable of simulating a single catchment or a system of hydrological linked subcatchments. The model of GIS based interface ArcSWAT defines the river network, the main point of outflow from the catchment and the distribution of subcatchments and hydrological response units (HRU). Subcatchments are spatially related to each other. HRUs are basically parts of each subcatchment with a unique combination of land use, soil, slope and land management and those are not spatially related. This allows modelling of different evapotranspiration (ET), erosion, plant growth, surface flow, water balance, etc for each subcatchment or HRU, thus increases accuracy of the simulations (Di Luzio et al., 2005). The number of HRU-s in each subcatchment was set by a minimum threshold area of 5%:5%:5% for land use, soil and slope classes, respectively. Classes that cover less than 5% of area are eliminated in order to minimise the number of HRU-s whilst not overly compromising on model accuracy. The river Reka catchment was delineated on 9 subcatchment and 291 HRUs while the river Dragonja catchment on 16 subcatchments and 602 HRUs.

Data type	Scale	Source	Description/properties
Topography	25m×25m	The Surveying and Mapping Authority of the Republic of Slovenia	Elevation, slope, channel lengths
Soils	Slovenia: 1:25,000 Croatia: 1:50,000	Ministry of Agriculture, Forestry and Food of the Republic of Slovenia (MAFFRS); University of Ljubljana; University of Zagreb	Spatial soil variability. Soil types and properties.
Land use	Slovenia: 1m×1m (Graphical Units of Agricultural Land) Croatia: 100m×100m (CORINE)	MAFFRS; European Environment Agency	Land cover classification and spatial representation
Land management	/	Chamber of Agriculture and Forestry of Slovenia; MAFFRS (Mihelič et al., 2009); Interviews with farmers	Crop rotations: planting, management, harvesting. Fertiliser application (rates and time)
Weather stations	Reka: 2 rainfall, 1 meteo (wind, temp., rain, humidity, solar) Dragonja: 3 rainfall, 1 meteo	Environment Agency of the Republic of Slovenia (EARS)	Daily precipitation, temperature (max., min.), relative humidity, wind, solar radiation.
Water abstraction	46 permits (136 points)	EARS	From surface and groundwater.
Waste water discharges	Reka: 2 points Dragonja: 1 point	EARS	Registered domestic, Industrial discharge
River discharge	Reka: 2 stations Dragonja: 1 station	EARS	Daily flow data (m^3 day^{-1})
River quality	Reka: 0 monitoring station; Dragonja: 1 monitoring station	EARS	Sediment ($mg\ l^{-1}$)

Table 1. Model input data sources for the Reka and Dragonja catchments

2.3 Model performance objective functions

The Pearson coefficient of correlation (R^2) (unit less) (1) describes the portion of total variance in the measured data as can be explained by the model. The range is from 0.0 (poor model) to 1.0 (perfect model). A value of 0 for R^2 means that none of the variance in the measured data is replicated by the model, and value 1 means that all of the variance in the measured data is replicated by the model. The fact that only the spread of data is quantified which is a major drawback if only R^2 is considered. A model that systematically over or under-predicts all the time will still result in "good" R^2 (close to 1), even if all predictions are wrong (Krause et al., 2005).

$$R^2 = \left(\frac{\sum_{i=1}^{n} (simulated_i - simulated_{average})(measured_i - measured_{average})}{\sqrt{\sum_{i=1}^{n} (simulated_i - simulated_{average})^2} \sqrt{\sum_{i=1}^{n} (measured_i - mesured_{average})^2}} \right)^2 \quad (1)$$

Function bR^2 is defined as coefficient of determination R^2 multiplied by the absolute value of the coefficient (slope) of the regression line (b) between simulated (S) and measured (M), with treatment of missing values (2). It allows accounting for the discrepancy in the magnitude of two signals (depicted by b) and their dynamics (depicted by R^2). The slope b is computed as the coefficient of the linear regression between simulated and measured, forcing the intercept to be equal to zero. The objective function is expressed as:

$$bR^2 = \begin{cases} |b| \times R^2 \; for\, b \le 1 \\ |b| \div R^2 \; for\, b > 1 \end{cases} \quad (2)$$

The Nash-Sutcliffe simulation efficiency index (E_{NS}) (unit less) (3) is widely used to evaluate the performance of hydrological models. It measures how well the simulated results predict the measured data. Values for E_{NS} range from negative infinity (poor model) to 1.0 (perfect model). A value of 0.0 means, that the model predictions are just as accurate as measured data (minimally acceptable performance). The E_{NS} index is an improvement over R^2 for model evaluation purposes because it is sensitive to differences in the measured and model-estimated means and variance (Nash & Sutcliffe, 1970). A disadvantage of Nash-Sutcliffe is that the differences between the measured and simulated values are calculated as squared values and this places emphasis on peak flows. As a result the impact of larger values in a time series is strongly overestimated whereas lower values are neglected.

$$\mathrm{E}_{NS} = 1 - \left(\frac{\sum_{i=1}^{n} (measured_i - simulated_i)^2}{\sum_{i=1}^{n} (measured_i - measured_{average})^2} \right) \quad (3)$$

Root Mean Square Error – RMSE (4) is determined by calculating the standard deviation of the points from their true position, summing up the measurements, and then taking the square root of the sum. RMSE is used to measure the difference between flow ($q^{simulated}$) values simulated by a model and actual measured flow ($q^{measured}$) values. Smaller values indicate a better model performance. The range is between 0 (optimal) and infinity.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (q_t^{measured} - q_t^{simulated})^2}{n}} \quad (4)$$

Percentage bias – *PBIAS* (%) (5) measures the average tendency of the simulated flows ($q^{simulated}$) to be larger or smaller than their measured ($q^{measured}$) counter parts (Moriasi et al., 2007). The optimal value is 0, and positive values indicate a model bias towards underestimation and vice versa.

$$PBIAS = \left(\frac{\sum_{i=1}^{n} (q_t^{measured} - q_t^{simulated})}{\sum_{i=1}^{n} (q_t^{measured})} \right) \cdot 100\% \quad (5)$$

Model calibration criteria can be further based on recommended percentages of error for annual water yields suggested from the Montana Department of Environment Quality (2005) that generalised information related to model calibration criteria (Table 2) based on a number of research papers.

Errors (Simulated-Measured)	Recommended Criteria
Error in total volume	10%
Error in 50% of lowest flows	10%
Error in 10% of highest flows	15%
Seasonal volume error (summer)	30%
Seasonal volume error (autumn)	30%
Seasonal volume error (winter)	30%
Seasonal volume error (spring)	30%

Table 2. Model calibration hydrology criteria by Montana Department of Environment Quality (2005)

For the detection of statistical differences between the two base scenarios and alternative scenarios Student t-test statistics should be used (α = 0.025, degrees of freedom (SP = n-1)), for comparing average annual value of two dependent samples at level of significance 0.05 (6). Where $\bar{x}$ is a sample arithmetic mean (alternative scenario), μ an average of the corresponding random variables (base scenario), s is sample standard deviation (alternative scenario) and n number of pairs (alternative scenario). Variable, which has approximately symmetrical frequency distribution with one modus class, is in the interval $\bar{x}$ ±s expected 2/3 of the variables and in $\bar{x}$ ± 2s approximately 95% of the variables and in $\bar{x}$ ± 3s almost all variables. Confidence interval ($l_{1,2}$) for Student distribution ($t_{\alpha/2}$) for all sample arithmetic means can be calculated (7).

$$t = \frac{\bar{x} - \mu}{s / \sqrt{n}} \tag{6}$$

$$l_{1,2} = \bar{x} \pm t_{\frac{\alpha}{2}}(n-1) \cdot \frac{s}{\sqrt{n}} \tag{7}$$

3. Sensitivity analysis

Sensitivity analysis limits the number of parameters that need optimization to achieve good correlation between simulated and measured data. The method of analysis in the SWAT model called ParaSol is based on the method of Latin Hypercube One-factor-at-a-Time (LH-OAT). ParaSol method combines the objective functions into a global optimization criterion and minimizes both of them by using the Shuffled Complex (SCE-UA) algorithm (van Griensven et al., 2006). The new scheme allows the LH-OAT to unmistakably link the changes in the output data of each model to the modified parameter (van Griensven et al., 2006).

Tool within the SWAT model can automatically carry out the sensitivity analysis without the measured data or with the measured data. The tool varies values of each model parameter within a range of (MIN, MAX). Parameters can be multiplied by a value (%), part of the value can be added to the base value, or the parameter value can be replaced by a new value. The final result of the sensitivity analysis are parameters arranged in the ranks, where the parameter with a maximum effect obtains rank 1, and parameter with a minimum effect obtains rank which corresponds to the number of all analyzed parameters. Parameter that has a global rank 1, is categorized as "very important", rank 2 – 6 as "important", rank 7 – 41 (i.e. the number of parameters in the analysis – i.e. flow 7 - 26) as "slightly important" and rank 42 (i.e. flow 27) as "not important" because the model is not sensitive to change in parameter (van Griensven et al., 2006).

Beside in the model build tool for the sensitivity analysis and calibration a special standalone tool called SWAT-CUP is available which includes all important algorithms (GLUE, PSO, MCMC, PARASOL and SUFI-2) of which Sequential Uncertainty Method (SUFI-2) has shown to be very effective in identifying sensitive parameters and calibration procedures (Abbaspour et al., 2007). With the right choice of a method and tool we can substantially shorten the process of parameter sensitivity identification.

Sensitivity analysis was performed for subcatchment 5 on the river Reka tributary Kožbanjšček and subcatchment 14 on the river Dragonja. This were the only points in both catchments where were alongside the river flow also sediment and nutrients concentrations measured. The presented analysis was performed for an average daily flow and sediments. Table 3 represents for each model the first 10 parameters that have the greatest impact on the model when they are changed. The sensitivity analyses demonstrated great importance of the hydrological parameters that are associated with surface and subsurface runoff. Parameter sensitivity ranking and value range is greatly dependent on the uncertainties originating in model simplification, in processes not included, unknown or unaccountable and in measured data errors or in time step of the measured data (daily, monthly, yearly).

Surlag represents the surface runoff velocity of the river and **Alpha_Bf** factor determines the share between the base and surface flow contribution to the total river flow. **Cn2** curve runoff determines the ratio between the water drained by the surface and subsurface runoff in moist conditions. **Ch_K2** describes the effective hydraulic conductivity of the alluvial river bottom (water losing and gaining). **Esco** describes evaporation from the soil and **Rchrg_Dp** fraction of groundwater recharge to deep aquifer. For the sediment modelling the most important parameters are **Spcon** and **Spexp** that affect the movement and separation of the sediment fractions in the channel. **Ch_N** – Manning coefficient for channel, determines the sediment transport based on the shape of the channel and type of the river bed material. **Ch_Erod** – Channel erodibility factor and **Ch_Cov** – Channel cover factor that has proved to be important for the Dragonja catchment. Soil erosion is closely related to the surface runoff hydrological processes (Surlag, Cn2). The analysis showed importance of the hydrological parameters that are associated with surface and subsurface runoff (Cn2, Surlag) and base flow (Alpha_Bf), suggesting numerous routes by which sediment is transported (Table 3).

Base model	Sensitivity Analysis Objective function (SSQR) Flow	Sediment	Category
Reka	Surlag	Spcon	Very important
	Alpha_Bf	Ch_N	Important (2-6)
	Cn2	Surlag	
	Ch_K2	Spexp	
	Esco	Cn2	
	Ch_N	Alpha_Bf	
Dragonja	Cn2	Spcon	Very important
	AlphaBf	Ch_Erod	Important (2-6)
	Ch_K2	Ch_Cov	
	RchrgDp	Ch_N	
	Esco	Spexp	
	Surlag	Surlag	

Table 3. SWAT parameters ranked by the sensitivity analysis for the Reka subcatchment 5 and the Dragonja subcatchment 14 (1998 - 2005)

4. Calibration and validation

Many of the model's input parameters cannot be measured for different reasons, such as high cost of equipment or lack of time or personnel which means that the model must be calibrated. During the model calibration parameters are varied within an acceptable range, until a satisfactory correlation is achieved between measured and simulated data. Usually, the parameters values are changed uniformly on the catchment level. However, certain parameters (Cn2, Canmx, Sol_Awc) are exceptions, because of the spatial heterogeneity. The variable to which the model is most sensitive should be calibrated first, that is usually hydrology. Firstly manual calibration, parameter by parameter, should be carried out with gradual adjustments of the parameter values until a satisfactory output results (E_{NS} and $R^2 > 0.5$) (Moriasi et al., 2007, Henriksen et al., 2003). This procedure may be time consuming for inexperienced modellers. In the process of autocalibration only the most sensitive parameters are listed that showed the greatest effect on the model outputs. For each of the parameter a limit range (max, min) has to be assigned.

Validation is the assessment of accuracy and precision, and a thorough test of whether a previously calibrated parameter set is generally valid. Validation is performed with parameter values from the calibrated model (Table 4) and with the measured data from another time period. Due to the data scarcity, the model was validated only for the hydrological part (flow). The river Reka sediment data covers only one year of daily observations, which was only enough for the calibration. For the river Dragonja a 14 years long data series of sediment concentrations were available, but the data was scarce (92 measurements). It should be pointed out that samples taken during monitoring represents only the current condition of the river in a certain part of the day (concentration in mg l^{-1}) which has to be recalculated to load, while the simulated value is a total daily transported load (kg day^{-1}) in a river.

Calibration of the daily flow for the rivers Reka (subcatchment 8) and Dragonja (subcatchment 14) catchments was performed for the period from 1998 to 2005. According to the availability of data we selected different periods for the daily flow validation of the Reka (1993–1997, 2006–2008) and Dragonja (1994–1996, 2006–2008). Due to the lack of data we performed the sediment calibration for the river Reka tributary Kožbanjšček (subcatchment 5) daily between 1. 7. 2008 – 30. 6. 2009 and for the river Dragonja (subcatchment 14) daily calibration (montly sampling frequency) for the period 1994 – 2008.

Parameter		Default value	Range	Calibrated values	
				Reka	**Dragonja**
1	Alpha_Bf	0.048	0–1	0.30058	0.45923
2	Canmx[1]	0	0–20	8, 4, 2	8, 4, 2
3	Ch_K2	D	0–150	7.0653	3.7212
4	Ch_N	D	0–1	0.038981	0.04363
5	Cn2	D*	–25/+25%	–8, –15 [2]	+14
6	Esco	0.95	0–1	0.8	0.75
7	Gw_Delay	31	0–160	131.1	60.684
8	Gw_Revap	0.02	0–0.2	0.19876	0.069222
9	Gwqmn	0	0–100	100	0.79193
11	Surlag	4	0.01–4	0.28814	0.13984
E_{NS}				**0.61**	**0.57**

Legend: [1] - forest, permanent crops, grassland + arable; [2] - subcatchment 1-2-5, subcatchment 3-4-6-7-8-9; D - depends on river channel characteristics; D*- depends on soil type, land use and modeller set up

Table 4. Hydrological parameters, ranges and final values selected for the model calibration for the rivers Reka and Dragonja catchments

4.1 Hydrology

Base flow simulations are an important part of the catchment model calibration (Moriasi et al., 2007). The total flow consists of a base and surface flow, where base flow constitutes a major proportion of the measured total flow, especially in dry periods. In order to conduct the comparison between simulated and measured base flow the estimation of both is needed. For the base flow calculation a Baseflow program was used that includes a method of Automated Base Flow Separation from total flow (Arnold et al., 1995). Separation for the measured flow showed that base flow contributes 28 to 45% or on average about 37% of the river Reka flow and 37 to 55% or on average about 46% of the river Dragonja flow (Table 5, Table 6; Fig. 2).

Catchment	Base flow separation pass Fr 1		Base flow separation pass Fr2	
	Measured	**Simulated**	**Measured**	**Simulated**
Reka	0.45	0.43	0.28	0.27
Dragonja	0.55	0.58	0.37	0.43

Table 5. Calculation of the percentages of the base flow from total flow with Baseflow Program for the calibration period 2001–2005 for the rivers Reka and Dragonja

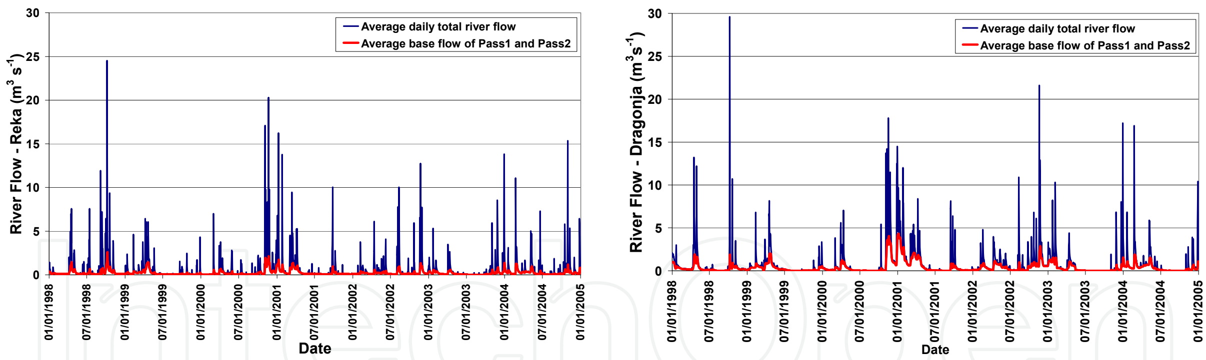


Fig. 2. Separation of base flow from the measured average daily flow ($m^3 s^{-1}$) of the rivers Reka and Dragonja (1998–2005)

Catchment	Year	Measured Flow (mm)		Simulated (mm)		Ratio Simulated/Measured	
		Total	Base	Total	Base	Total	Base
Reka	2001	700	289	761	317	1.09	1.10
	2002	587	215	512	177	0.87	0.82
	2003	455	162	415	122	0.91	0.76
	2004	717	267	614	202	0.86	0.76
	2005	513	187	461	175	0.90	0.93
	Average	*595*	*224*	*553*	*199*	*0.93*	*0.89*
Dragonja	2001	380	222	367	228	0.97	1.03
	2002	327	148	273	124	0.83	0.84
	2003	217	93	231	109	1.07	1.18
	2004	246	114	264	138	1.07	1.21
	2005	205	107	174	93	0.85	0.87
	Average	*275*	*137*	*262*	*139*	*0.95*	*1.02*

Table 6. Comparison of measured and simulated average annual sums of total and base flow (mm) for the calibration period (2001–2005) for the rivers Reka and Dragonja

Daily calibration objective functions show that the simulated total flows are within the acceptable range (Table 7, Fig. 3). Correlation coefficient (R^2) for a daily flow is influenced by low flows. Official measurements of a flow showed that on certain days the flow was not present or it was negligible. Model does not neglect extremely low flows, as is evident from the cumulative distribution of the flow (Fig. 3). Errors in flow measurements, in the worst case may be up to 42 % and in best case up to 3 % of the total flow (Harmel et al., 2006).

The E_{NS} values of flow fall into the category of satisfactory results (Moriasi et al., 2007, Henriksen et al., 2003), R^2 values fall into the category of good results, RMSE into the category of very good results (Henriksen et al., 2003) and PBIAS into the category of very good, good and satisfactory results (Moriasi et al., 2007). The reasons for lower results of the objective functions in the validation lie in the representation of the soil, rainfall and in the river flow data uncertainty.

	Reka				Dragonja			
	Calibration		Validation (Total Flow)		Calibration		Validation (Total Flow)	
Objective function	Base Flow	Total Flow	1993 - 1997	2006 - 2008	Base Flow	Total Flow	1994 - 1996	2006 – 2008
E_{NS}	0.61	0.61	0.39	0.69	0.55	0.57	0.45	0.42
R^2	0.72	0.64	0.57	0.70	0.66	0.59	0.49	0.49
RMSE	0.13	0.82	1.21	0.74	0.35	1.06	1.98	1.50
PBIAS	-12.79	7.04	-14.19	19.40	1.49	4.69	23.15	-3.31

Table 7. Daily time step river flow performance statistics for the rivers Dragonja and Reka for the calibration (2001-2005) and validation periods

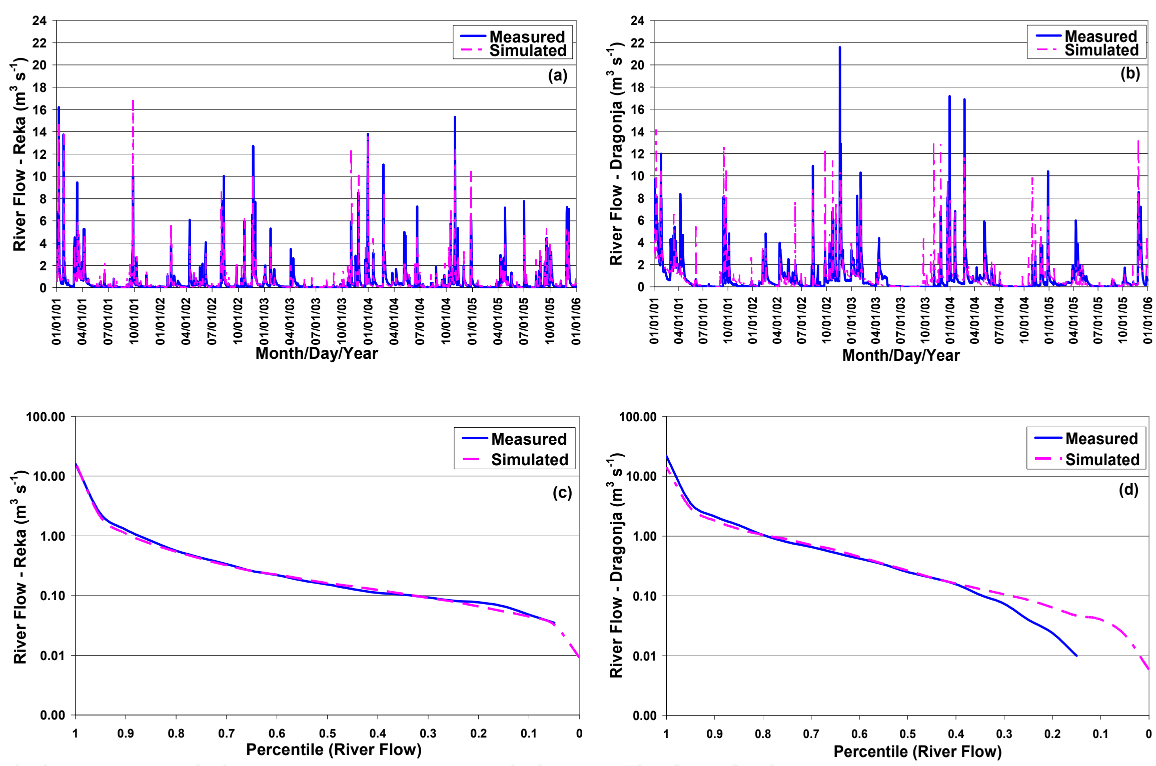


Fig. 3. Comparison between simulated (SWAT) and daily measured flows (m^3 s^{-1}) (a, b) and cumulative distribution by percentiles (c, d) of daily river flows for the calibration period (2001-2005)

4.2 Sediment

Parameters used for the sediment calibration were Spcon, Spexp, Ch_Erod, Ch_Cov and Usle_P (USLE equation support practice (P) factor). Simulation results for the river Reka show lower E_{NS} = 0.23 and a good result in predicting the variability of $E_{NSpercentile}$ = 0.83 (Table 8, Fig. 4). In the case of Dragonja, model achieved good results for E_{NS} = 0.70 and $E_{NSpercentile}$ = 0.73. Simulated PBIAS values fall for both catchments within the category of very good results as deviation is less than 15% (Moriasi et al., 2007) (Table 8, Fig. 4). Errors in typically measured sediment data can be on average around 18% and in worst and best case up to 117% or down to 3%, respectively (Harmel et al., 2006).

Parameter		Default	Range	Calibrated values	
Sediment				***Reka – Kožbanjšček***	***Dragonja***
1	Spcon	0.0001	0.0001–0.01	0.002	0.002
2	Spexp	1	1–1.5	1.3	1
3	Ch_Erod	0	0–1	0.092	0,06
4	Ch_Cov	0	0.05–0.6	0.1	0,1
5	Usle_P	1	0–1	slope dependent	slope dependent
E_{NS}				**0.23**	**0.70**
E_{NS} *percentile*				**0.83**	**0.73**
R^2				**0.24**	**0.80**
RMSE				**10.35**	**19.81**
PBIAS				**–0.15**	**–6.33**

Table 8. Calibrated sediment parameters, their ranges and the final values that are chosen for the model calibration periods (Reka Jul. 2008 – Jun. 2009; Dragonja 1994 - 2008)

Majority of the sediment in the Reka catchment eroded in the winter and early spring, when soils are in combination with tillage and weather conditions highly exposed to erosion (Fig. 4). In the Dragonja catchment it is apparent that monitoring scheme until the year 2004 was not adequately optimised in a way to capture the full range of possible daily situations, causing problems during calibration and disabling validation. Daily eroded curve shows the maximum erosion in the autumn, winter and early spring, when the area receives the

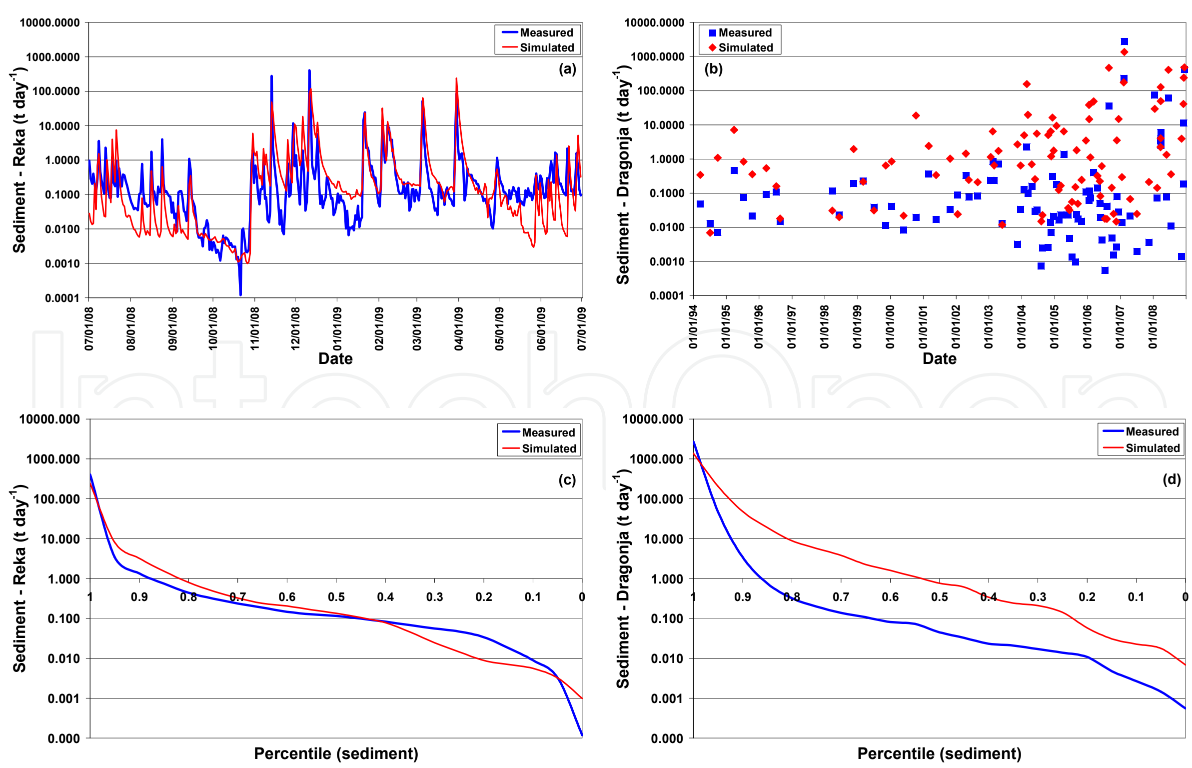


Fig. 4. Comparison between simulated and measured daily loads (t day-1) of sediment (a, b) and cumulative distribution by percentiles (c, d) for the river Reka - Kožbanjšček (Jul. 2008-Jun. 2009) and river Dragonja (1994–2008) on logarithmic scale

majority of precipitation. During this period soils get quickly saturated with low evapotranspiration. Low hydraulic conductivity of the soils (surface flow dominates) accompanied with higher rainfall intensities can result in flash floods. However, it is necessary to draw attention to the lack of soil data that would better describe the processes in the catchments. It is important to note that the measured sediment loads (day t^{-1}) are calculated from a certain part of the day sampled concentration (mg l^{-1}) using the mean daily flow (m^3 day^{-1}), creating uncertainty in the application of this type of data. Terracing of steep slopes where agricultural production takes place is common practice in both areas. As terraces significantly reduce surface runoff and consequently erosion Usle_P parameter values are adapted (Table 9).

Slope (%)	Usle_P (arable, olive grove, vineyard, orchard)	Usle_P (grassland)
1–10	0.55	0.55
11–20	0.70	0.70
21–35	0.06 - terraces	0.75
36–50	0.07 - terraces	0.80
> 51	0.08 - terraces	0.85

Table 9. Usle_P factor for agricultural land use at different slopes and for terraces

4.3 Model performance indicators

Important model performance indicators of the water balance for correct representation of flow, sediment and chemicals transport and losses are evapotranspiration (ET) and Soil Water Content (SWC) through infiltration (lateral, groundwater flow) and surface run-off. As evapotranspiration is a function of crop growth only a proper simulation of crop growth and management can ensure realistic modelling of evapotranspiration and nutrients within a river catchment. Sediment erosion and infiltration of chemicals through the soil profile depends on the share of water between surface runoff and water entering and moving through the soil profile in terms of percolation. Before sediment and chemicals modelling is attempted a correct partitioning of water in these three phases is required, apart from the requirement for a match of predicted and observed stream flow.

Evapotranspiration is a primary mechanism by which water is removed from the catchment. It depends on air temperature and soil water content. The higher the temperature, the higher is potential evapotranspiration (PET) and consequently ET, if there is enough of water in the soil. A simple monthly water balance between monthly precipitation and PET showed that average monthly water balance in the Reka catchment (station Bilje) is negative between May and August (Fig. 5). In the Dragonja catchment (station Portorož) water balance is negative from April to August (growing season) (Fig. 5).

Water that enters the soil may move along one of the several different pathways. It may be removed by plant uptake or evaporation; it may percolate past the bottom of the soil profile or may move laterally in the profile. However, plant uptake removes the majority of water that enters the soil profile (Neitsch et al., 2005). The SWC will be represented correctly if crops are growing at the expected rate and soils have been correctly parameterized. Figure 6 shows the SWC and precipitation of selected HRUs No. 38 (Reka) and No. 182 (Dragonja), with a silt clay soils, with the prevailing surface runoff and slow lateral subsurface flow. Water in soil exits the field capacity in the spring and return to that state in the autumn (Fig. 6). Soils in the summer are often completely dry with occasional increasing induced by storms.

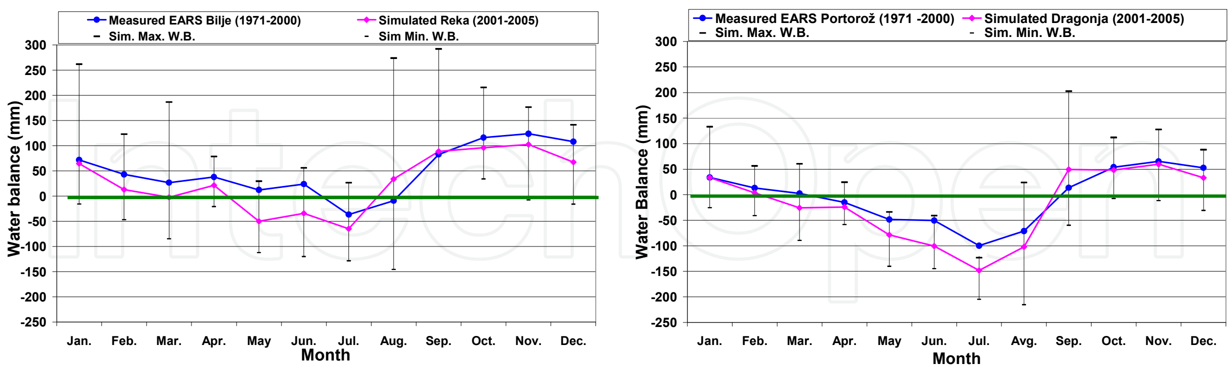


Fig. 5. Comparison of simulated and measured (Environment Agency of Republic of Slovenia - EARS) water balance (mm) for the Reka subcatchments 8 and Dragonja subcatchment 14.

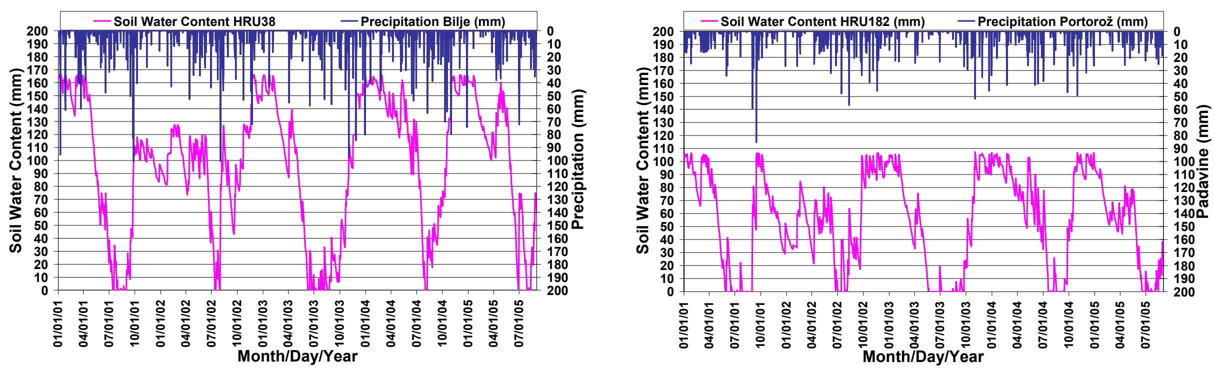


Fig. 6. Comparison of simulated soil water content (mm) for the HRU No. 38 (Reka) and HRU No. 182 (Dragonja) and observed precipitation (mm) in the calibration period (2001–2005)

The plant growth component of SWAT is a simplified version of the plant growth model. Phenological plant development is based on daily accumulated heat units, leaf area development, potential biomass that is based on a method developed by Monteith, a harvest index is used to calculate yield, and plant growth that can be inhibited by temperature, water, N or P stress. (Neitsch et al., 2005). In the crop database a range of parameters can be changed to meet the requirements for optimal plant growth. We used default SWAT database parameters that were additionally modified (Frame, 1992). An example crop growth profile for development of leaf area index (LAI) and plant biomass (BIOM) for vineyard is presented on Fig. 7.

5. Climate change scenarios

The base of climate scenarios was taken from the research on the transfer of global climate simulations on the local level (Bergant, 2003). This is currently the only one climate change study for both research areas where climate changes are described with specific numeric

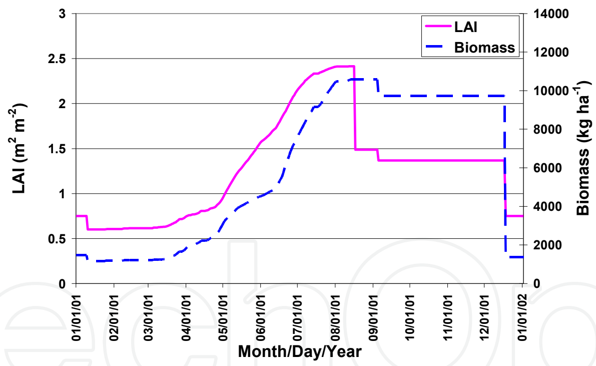


Fig. 7. Simulated vineyard biomass growth (kg ha^{-1}) and leaf area index (m^2 m^{-2}) for the HRU No. 38 in the river Reka catchment

data. Majority of SWAT model studiesthat predict the effects of climate changes on the environment are focused on the proper projection of global, general and regional circulation climate models on the local level (Gassman et al., 2007).

Bergant (2003) research is concentrated on the empirical reduction of global regional scale climate models from REG 3 prediction level to local level. Accordingly he used several methods, from which one was for further analysis where partial least squares regression (PLS) method with a two-dimensional (2PLS) and three-dimensional (3PLS) matrix were selected. Average value between the 3PLS and 2PLS was used for calculation of changes in precipitation (%) and 3PLS method for the temperature (°C) change calculation. Further, average change between two IPCC socio-economic scenarios (A2 - global-economic and B2 - regional environmental) was calculated for the base scenario (Bergant, 2003). The final results (Table 10) are absolute change in temperature (°C) and percentage change in

Period of the year / IPCC Scenario	**Scenario**					
	2030		**2060**		**2090**	
	Reka	Dragonja	Reka	Dragonja	Reka	Dragonja
	Temperature (change in °C)					
Warm period / A2	1.70	1.00	2.65	1.55	5.90	2.70
Warm period / B2	1.60	0.90	2.65	1.60	4.30	2.10
Average / A2B2	*1.65*	*0.95*	*2.65*	*1.58*	*5.10*	*2.40*
Cold period / A2	1.25	1.35	2.85	2.60	3.85	4.15
Cold period / B2	1.40	1.40	2.45	2.25	3.30	3.05
Average /A2B2	*1.33*	*1.38*	*2.65*	*2.43*	*3.58*	*3.60*
	Precipitation (change in %)					
Warm period / A2	–12.00	–6.00	–22.50	–13.50	–35.00	–21.50
Warm period / B2	–15.50	–7.50	–23.00	–14.00	–31.50	–17.50
Average / A2B2	*–13.75*	*–6.75*	*–22.75*	*–13.75*	*–33.25*	*–19.50*
Cold period / A2	–16.00	+3.50	–16.00	+8.50	–24.00	+16.00
Cold period / B2	–13.50	+5.00	–21.00	+10.00	–18.00	+14.00
Average /A2B2	*–14.75*	*+4.25*	*–18.50*	*+9.25*	*–21.00*	*+15.00*

Table 10. The used climate change data on temperature (°C) and precipitation (%) – adapted from Bergant (2003)

precipitation (%) for warm (April - September) and cold (October - March) half of the year for the three time periods (2001-2030, 2031-2060, 2061-2090). These changes were used for the modification of existing databases of daily weather data. When transferring the regional models on the local level there are a number of uncertainties (Bergant, 2003) related to downscaling and representation of local features. Forecasts of temperature are more reliable than precipitation since research areas are located in the rough hilly terrain and at the interface between Mediterranean and Alpine climate. This strongly influences the local weather, especially in the warm half of the year characterized by storms. One of the uncertainties is associated with the input data, since we only had information on changes in precipitation and temperatures, but none on wind, solar radiation and relative humidity. For the research areas they are predicted to be, in terms of agriculture and water balance, the most problematic years, when temperatures are higher and rainfall are lower than long-term average (Bergant & Kajfež Bogataj, 2004).

For each catchment were designed three scenarios (2030, 2060 and 2090). In the process of modelling climate change we have not changed any of the calibrated SWAT model parameters. The purpose of the scenarios is to investigate the impacts of changing climatic conditions in catchments with Flysch soils on the river flow and sediment load in the rivers.

6. Results and discussion

Base and climate scenarios simulation were carried out for the Reka catchment for the period of 18 years (1991-2008) with three years warm up period (1991-1993) and for the Dragonja catchment for the period of 17 years (1992-2008) with two years warm up period (1992-1993). Long time period is important for smoothing the effects caused by extreme meteorological events (storms) or to exclude effects of dry or wet periods. Warm up period is essential for stabilisation of parameters as the initial results can vary significantly from the observed values. In this period the model deposits sediment in the river network and fills the soil profile with water before simulation results can be considered realistic. All outputs from this period of time are excluded from statistical analysis.

The base scenario indicates a high average annual variability in the transport of the sediment in the river flow (Table 11). The standard deviations for the Reka subcatchment 8 reveal that 2/3 of the transported sediment quantities are expected in the interval 1 844 ± 1 075 t sediment year^{-1}, and for the Dragonja subcatchment 14 in the interval 4 804 ± 1 576 t sediment year^{-1}.

Catchment/subcatchment	Average	Median	Standard deviation	Min.	Max.
Flow (m^3 s^{-1})					
Reka/8	0.57	0.56	0.21	0.27	1.00
Dragonja/14	0.80	0.78	0.21	0.42	1.11
Sediment (t year^{-1})					
Reka/8	1 844	1 576	1 075	571	4 185
Dragonja/14	4 804	4 934	1 576	1 917	7 734

Table 11. Average annual flow (m^3 s^{-1}) and river load of sediment (t year^{-1}) for the Reka subcatchment 8 and Dragonja subcatchment 14 (1994–2008)

6.1 Climate change and river flow

Climate scenarios results relative to the base scenario show a reduction of average annual flows in the river in all periods (2030, 2060, 2090) for 29%, 41% and 55%, respectively (Table 12). Reduction of average flow was detected in the Dragonja catchment however they are less pronounced. Figure 8 shows the distinct change towards lower average flow in the summer and towards higher average flow in the winter months. Student t-statistics for comparison between base and climate scenarios, the average annual total flow shows differences between scenarios for the river Reka are highly statistically significant (Table 13). Differences for the river Dragonja are not statistically significant.

Catchment/ subcatchment	**Average annual percentage change (%)**		
	2030	2060	2090
River Flow			
Reka/8	–29.08	–40.69	–55.07
Dragonja/14	–3.16	–5.46	–6.53
Sediment			
Reka/8	–36.70	–51.60	–69.58
Dragonja/14	–29.93	–27.32	–28.12

Table 12. Impacts (change in %) of climate change scenarios on the river flow and sediment load in the watercourse; compared to the baseline scenario

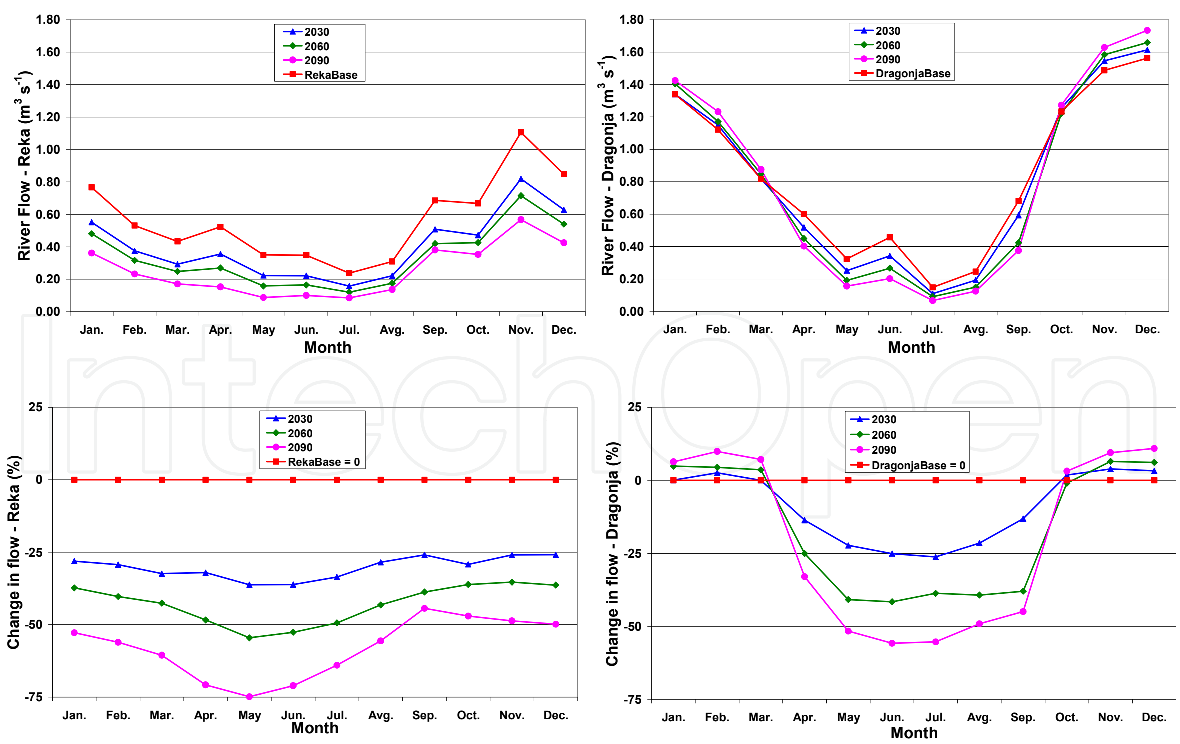


Fig. 8. Change in average monthly flow ($m^3 s^{-1}$, %) between the base (Base = 0) and climate change scenarios for the Reka subcatchment 8 and Dragonja subcatchment 14 (1994–2008)

Scenario	**Student t-test** (Significance level 0.05) Student distribution of the sample with n-1 degrees of freedom α=0.025, SP=14, t_α=2.145			
	Reka – subcatchment 8		**Dragonja – subcatchment 14**	
	Flow	**Sediment**	**Flow**	**Sediment**
2030	–4.046	–3.545	–0.464	–4.656
2060	–6.788	–6.888	–0.783	–3.427
2090	–12.545	–13.450	–0.842	–3.313

Note: The results of the scenarios are statistically significantly different from the base scenario, if the value of Student t-test exceeds t_α = 2.145. If the value is negative, scenario is reducing the quantities in the river flow, and vice versa.

Table 13. Review of statistically significant results of Student t-statistics for average annual flow and average annual load of sediment

Climate changes in the river Reka catchment are forecasted to be more drastic, because of the temperatures rise and precipitation decrease by 500 mm by the end of the 21st century. Furthermore, the average annual potential ET is forecasted to be increased from 1044 mm (Base) to 1219 mm (2090) and actual ET is forecasted to be reduced by more than 100 mm. Consequently, average annual flow would be reduced by 340 mm. Average annual flow for the river Reka in 2090 (268 mm) would get closer to the present flow of the river Dragonja (265 mm). In the Dragonja catchment, there are lower summer precipitations aligned with higher winter precipitations, leading to annual differences between scenarios of only a few millimetres.

6.2 Climate change and sediment

Climate scenarios percentage change in average annual sediment load in the river flow is lower as compared to the base scenario. For Reka catchment the sediment load for the scenarios 2030, 2060 and 2090 in the river flow are lower by 37%, 52% and 70%, respectively (Table 12). Statistical method showed the climate scenario differences for sediment load in the river Reka which is significantly different from baseline scenario (Table 13; Fig. 9)

For the Dragonja catchment the average annual sediment loads for the scenarios 2030, 2060 and 2090 in the river flow are 30%, 27% and 28% lower, respectively (Table 12). Statistical method showed that the differences in sediment loads transferred in the Dragonja river flow significantly differ from the base scenario (Table 13; Fig. 9).

6.3 Discussion and scenario evaluation

Statistically significant differences between the base and climate scenarios which are particularly pronounced in the Reka catchment are expected, as the decline in precipitation contributes to the reductions in surface flow and thereby to the reductions in erosion of soil particles. Climate models forecast less summer and more winter precipitation for the Dragonja catchment (Bergant, 2003); however the differences between seasons are only a few percent (2-5%) (Table 14). Lower summer precipitation, when majority of agricultural activities are taking place, and high proportion of modelled forest (74%) and grassland (19%),

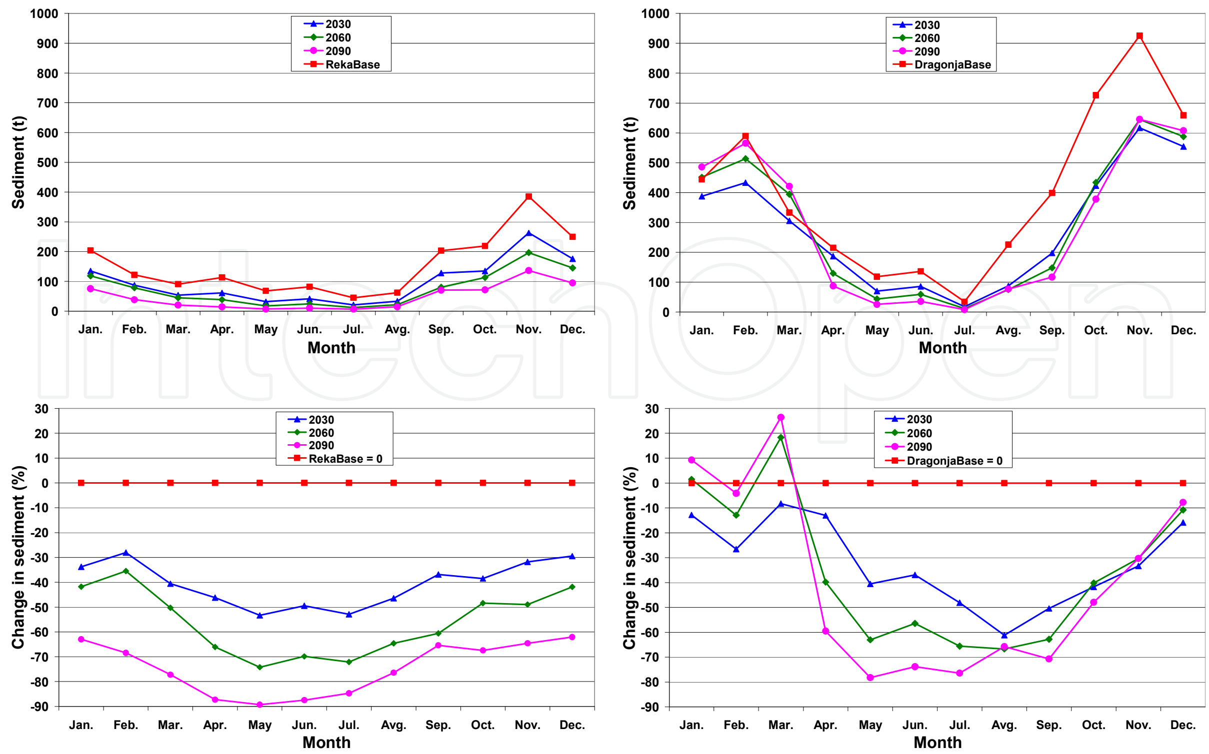


Fig. 9. Change in average monthly river loads of sediment (t, %) between the base (Base = 0) and climate change scenarios for the Reka subcatchment 8 and Dragonja subcatchment 14 (1994–2008)

both less susceptible for erosion, have resulted in a decrease of the average annual sediment loads. But positive consequences reflected in the sediment load reduction, may also be of concern due to reduction of the water quantities (Xu et al., 2008).

Simulated sediment loads in the climate scenarios are also lower because of less precipitation in the summer when agricultural activities are taking place (fertilizer, mulching, tillage). With increasing temperatures the shift in the growing season is expected like earlier times in the year (Ficklin et al., 2009) providing better conditions for growth of vegetation and preventing soil erosion. This means cultivation of the land during the major precipitation events, which can result in an increased release of soil particles and nutrients (Bouraoui et al., 2002). It is expected that there will be strong influence of the climate changes on higher frequency and quantity of extreme precipitation events and drought lengths, which will greatly affect the water cycle (Wilby et al., 2006). One or two major events may substantially contribute to total average annual quantity of sediment (Ramos & Martinez-Casanovas, 2008).

When interpreting the concentrations, we need to have in mind the geological and soil characteristics of the catchment. There is also a question, whether to consider set guide levels for the rivers that does not represent an economic interest (Lohse, 2008); however rivers are not only economic asset. Careful evaluation of each scenario has to be performed according to its positive and negative issues on the environment, agriculture, social life and economy (Glavan et al., 2011, Volk et al., 2009). Climate change scenarios have a significant impact on the concentration of sediment, since both catchments would decrease by the legislation recommended concentration of 25 mg l^{-1} (Table 14).

		Average annual sediment concentration (mg l^{-1})	
		REKA – subcatchment 5	DRAGONJA – subcatchment 14
Measured		***32.6***	***29.3***
Scenarios	2030	20.5	20.5
	2060	15.5	21.3
	2090	9.9	21.1

A guide concentration for the sediment in the rivers set legislation is **25 mg l^{-1} (**Regulation of surface water quality for freshwater fish species - Official Gazette of Republic of Slovenia 46/02).

Table 14. Impacts of the climate change scenarios on the average annual sediment concentration (mg l^{-1})

Based on the obtained data and model calculations it can be concluded that climate changes, if used values are realized, would significantly affect quantity of water in the river Reka flow and significantly reduce sediment loads in the rivers Reka and Dragonja. The data shows that by the end of the century the average annual precipitation in the Reka catchment would approach to the precipitation in the Dragonja catchment. Forecasted reductions would result in a significant decline of flow and extension of the dry riverbed of the River Reka, which is now rarely longer than a week or two, and change ecological conditions for the organisms. Climate change in the river Dragonja would lead to extension of the dry riverbed period in the warm half of the year, which would negatively affect the ecosystem.

In the future, the changing status of ecosystem conditions of water bodies as a result of climate change will require special attention by the relevant public agencies and governmental departments (Purkey et al., 2007), by enforcement of appropriate legislation and regulations (Wilby et al., 2006). The results of these scenarios should be considered only as one possible scenario, but only if climate change would really change in the direction of used temperature and precipitation data.

7. Conclusions

The application of the SWAT model in the Reka and Dragonja catchment has demonstrated that SWAT is able to represent the hydrological behaviour of the heterogeneous catchments. Within the constraints of the available data the model was able to represent the sediment loads, concentrations and cumulative distributions. However, there are a number of issues that these model results can demonstrate as important in the water pollution control.

7.1 Strengths

The SWAT model is easily available on-line and enables water managers to model the quantity of surface water and quality of catchments worldwide. It is a comprehensive model integrating surface land and channel environmental processes. It combines studies of water quantity (river discharge, surface flow, subsurface flow, lateral flow, base flow, drains, irrigation, reservoirs, lakes), water quality (weather, erosion, plant growth, nutrients cycles, pesticides, soil temperatures, agricultural land management, crop production, urban land management, agri-environmental measures) and climate change. It is capable of yearly, monthly, daily or sub-hourly simulation over long periods.

Over 20 years of work on model development has resulted in several tools, interfaces and support software for SWAT. SWATeditor is a standalone program which reads the project database generated by ArcSWAT interface to edit SWAT input files, execute SWAT run, perform sensitivity, autocalibration and uncertainty analysis. VIZSWAT is a visualization and analysis tool which analyzes model results generated from all versions of the model. MWSWAT is an interface to the SWAT 2005 model and a plug-in for MapWindow, an Open Source GIS system which runs under the Windows operating system. The SWAT Check program helps to identify potential model input parameters issues. Sensitivity Analysis and Manual and Auto-calibration tool incorporated in to the model greatly helps modellers with automated procedures to define and change the model parameters and perform optimal calibration. SWAT-CUP is a standalone, public domain computer program for sensitivity analysis, calibration, validation, and uncertainty analysis of SWAT models. The program links GLUE, ParaSol, SUFI2, MCMC, and PSO procedures to SWAT.

Flexible framework that allows simulation of agri-environmental measures and best management practices is essential strength of the SWAT model. Simulations of measures and practices can be in the majority of cases be directly linked with changing model parameters. Management files allow the modeller to model crops in rotations, fertilizer and manure application rates and timing, tillage, sowing and harvesting time, type of farming tools and machinery, irrigation management, buffer strips, terraces etc.

7.2 Weaknesses

The main weakness of the model is a non-spatial representation of the HRU inside each subcatchment. This kept the model simple and supported application of the model to almost every catchment. Land use, soil and slope heterogeneity of the model is accounted through subcatchments. This approach ignores flow and pollutants routing between HRUs.

Wide range of different data needs to be obtained to run the model and numerous parameters needed to be modified during the calibration which discourage modellers to use SWAT. However, environment is a complex system and disregarding or underestimation of importance of parameters could lead to inaccurate model results and evaluations.

More extensive use of the model would be expected with adding more groundwater routines and algorithms or with permanent coupling of the model with groundwater model.

The model does not allow simulations of multicultural plant communities which are common in organic farming, grasslands and forests as they were originally developed for monocultures.

Sensitivity analysis, manual and auto-calibration tools in the SWAT model is time demanding when modelling complex catchments with numerous HRUs. This tool should be upgraded at least with visual and objective functional representation of the results. The SWAT-CUP tool is a significant improvement for the calibration procedures, however coupling of SWAT and SWAT-CUP is needed to increase efficiency of modelling.

7.3 Opportunities

There are many opportunities outside the SWAT model that provide unique possibility for growth and change of the model in future. Numerous environmental problems due to industrial, mining and land use policy resulted in stricter government legislations around the world (USA – Clean Water Act, EU - WFD) encouraging the use of the models like SWAT.

Non-spatial representation of the HRUs requires new studies on water, sediment and nutrients, routing across landscapes by surface, subsurface and base flow, to allow the model to carry out realistic simulation of the HRU pollutants inter-transfer, source areas, buffer zones, etc.

7.4 Threats

Threats may adversely impact the model performance and use, if they are not addressed. In the process of building a model several adjustments of the parameters need to be made in order to improve simulations. Adjustments are usually not measurable and are made using the modellers' experiences, best knowledge and subjective assessment of the study area. This can have important implications on overall performance and outcome of the model and its suitability for certain case studies which are difficult to quantify.

Measured monitoring data is usually expressed and presented in concentrations (mg l^{-1}) and has to be recalculated with the measured flow data to make loads comparable with model outputs. This can be a source of errors especially if the monitored data, e.g. flow, sediment, nutrients, is not measured properly or is sampled at low frequency rate.

In highly managed catchments the unknown and unaccountable activities like transport construction sites, water abstraction, reservoirs, dams, waste treatment plants, waste and chemicals dumping in the rivers can add substantial error to the model outputs.

Spatial resolution of land use, soil, slope and weather data are usually not set on the same scale. This leads us to the conclusion that spatial results are as good as the data with lowest resolution. Actual on-site distribution of crops, crop rotations and actual management practices (sowing and harvest dates and fertiliser application dates and rates) is in large and medium catchments a challenge to represent spatially. Combined with uncertainties in the soil spatial and attribute data may significantly affect proper modelling of water balance and sediment transport in the catchments.

Model results and their interpretation by the modeller must lead to constructive discussion, which aims to achieve and maintain good water quality in research catchments, which is the objective of the Water Framework Directive and other legislations related to water.

8. Acknowledgments

Financial support for this study was provided by the Slovenian Research Agency founded by the Government of the Republic of Slovenia. Contract number: 1000-06-310163.

9. References

Abbaspour, K.C.; Yang, J.; Maximov, I.; Siber, R.; Bogner, K.; Mieleitner, J.; Zobrist, J. & R. Srinivasan (2007). Modelling hydrology and water quality in the pre-alpine/alpine Thur watershed using SWAT. *Journal of Hydrology,* Vol.333, pp. 413-430

Arnold, J.G.; Allen, P.M.; Muttiah, R. & Bernhardt, G. (1995). Automated Base Flow Separation and Recession Analysis Techniques. *Ground Water*, Vol.33, No.6, pp. 1010–1018

Arnold, J.G.; Srinivasan, R.S.; Muttiah, R.S. & Williams, J.R. (1998). Large area hydrological modelling and assessment Part I: Model development. *Journal of the American Water Resources Association*, Vol.34, No.1, pp. 73–89

Barlund, I.; Kirkkala, T.; Malve, O. & Kamari, J. (2007). Assessing SWAT model performance in the evaluation of management actions for the implementation of the Water Framework Directive in a Finnish catchment. *Environmental Modeling Software,* Vol.22, pp. 719–724

Bouraoui, F.; Galbiati, L. & Bidoglio, G. (2002). Climate change impacts on nutrient loads in the Yorkshire Ouse catchment (UK). *Hydrology and Earth System Sciences*, Vol.6, No.2, pp. 197–209

Bergant, K. (2003). Projections of global climate simulations to local level and their use in agrometeorology. Doctoral thesis. University of Ljubljana, Ljubljana

Bergant, K.; Kajfež Bogataj, L. (2004). Nekatere metode za pripravo regionalnih scenarijev podnebnih sprememb = Empirical downscaling method as a tool for development of regional climate change scenarios. *Acta agriculturae Slovenica*, Vol.83, No.2, pp. 273–287

Bergant, K.; Kajfež Bogataj, L. (2005). N–PLS regression as empirical downscaling tool in climate change studies. *Theoretical and Applied Climatology*, Vol.81, pp. 11–23

Di Luzio, M.; Arnold, J. G. & Srinivasan, R. (2005). Effect of GIS data quality on small watershed streamflow and sediment simulations. *Hydrolgical Processes*, Vol.19, No.3, pp. 629–650

Ficklin, D.L.; Luo, Y.; Luedeling, E. & Zhang, M. (2009). Climate change sensitivity assessment of a highly agricultural watershed using SWAT. *Journal of Hydrology*, Vol.374, pp. 16–29

Frame, J. (1992). *Improved grassland management*. Farming Press Books, Wharfedale

Garen, D.C. & Moore, D.S. (2005). Curve number hydrology in water quality modeling: uses, abuses, and future directions. *Journal of the American Water Resources Association*, Vol.41, No.6, pp. 1491–1492

Gassman, P.W.; Reyes, M.R.; Green, C.H. & Arnold, J.G. (2007). The soil and water assessment tool: Historical development, applications, and future research direction. *Transactions of the ASABE*, Vol.50, No.4, pp. 1211–1250

Glavan, M.; White, S. & Holman, I. (2011). Evaluation of river water quality simulations at a daily time step – Experience with SWAT in the Axe Catchment, UK. *CLEAN – Soil, Air, Water*, Vol.39, No.1, pp. 43–54

Harmel, R.D.; Potter, S.; Ellis, P.; Reckhow, K.; Green, C.H. & Haney, R.L. (2006). Compilation of measured nutrient load data for agricultural land uses in the US. *Journal of American Water Resources Association*, Vol.42, pp. 1163–1178

Hejzlar, J.; Anthony, S.; Arheimer, B.; Behrendt, H.; Bouraoui, F.; Grizzetti, B.; Groenendijk, P.; Jeuken, M.; Johnsson, H.; Lo Porto, A.; Kronvang, B.; Panagopoulos, Y.; Siderius, C.; Silgram, M.; Venohrd, M. & Žaloudíka, J. (2009). Nitrogen and phosphorus retention in surface waters: an inter-comparison of predictions by catchment models of different complexity, *Journal of Environmental Monitoring*, Vol.11, pp. 584–593

Henriksen, H.J.; Troldborg, L.; Nyegaard, P.; Sonnenborg, O. T.; Refsgaard, J. C. & Madsen, B. (2003). Methodology for construction, calibration and validation of a national hydrological model for Denmark. *Journal of Hydrology*, Vol.280, pp. 52–71

Knutti, R.; Allen, M.R.; Friedlingstein, P.; Gregory, J.M.; Hegerl, G.C.; Meehl, G.A.; Meinshausen, M.; Murphy, J.M.; Plattner, G.-K.; Raper, S.C.B.; Stocker, T.F.; Stott, P.A.; Teng, H. & Wigley, T.M.L. (2008). A review of uncertainties in global temperature projections over the twenty-first century. *Journal of Climate*, Vol.21, No.11, pp. 2651–2663

Krause, P.; Boyle, D.P. & Bäse, F. (2005). Comparison of different efficiency criteria for hydrological model Assessment. *Advances in Geosciences*, Vol.5, pp. 89–97

Kronvang, B.; Borgvang, S. A. & Barkved, L. J. (2009a). Towards European harmonised procedures for quantification of nutrient losses from diffuse sources – the EUROHARP project. *Journal of Environmental Monitoring*, Vol.11, No.3, pp. 503–505

Kronvang, B.; Behrendt, H.; Andersen, H.; Arheimer, B.; Barr, A.; Borgvang, S.; Bouraoui, F.; Granlund, K.; Grizzetti, B.; Groenendijk, P.; Schwaiger, E.; Hejzlar, J.; Hoffman, L.; Johnsson, H.; Panagopoulos, Y.; Lo Porto, A.; Reisser, H; Schoumans, O.; Anthony, S.; Silgram, M.; Venohr, M. & Larsen, S. (2009b). Ensemble modelling of nutrient loads and nutrient load partitioning in 17 European catchments. *Journal of Environmental Monitoring*, Vol.11, pp. 572–583

Krysanova, V. & Arnold, J.G. (2008). Advances in ecohydrological modelling with SWAT—a review. *Hydrological Sciences–Journal des Sciences Hydrologiques*, Vol.53, No.5, pp. 939–947

Lohse, K.A.; Newburn, D.A.; Opperman, J.J. & Merenlender, A.M. (2008). Forecasting relative impacts of land use on anadromous fish habitat to guide conservation planning. *Ecological Applications*, Vol.18, No.2, pp. 467–482

Meehl, G.A.; Washington, W.M.; Collins, W.D.; Arblaster, J.M.; Hu, A.; Buja, L.E.; Strand, W.G. & Teng, H. (2005). How much more global warming and sea level rise? *Science*, Vol.307, pp. 1769–1772

Mihelič, R.; Čop, J.; Jakše, M.; Štampar, F.; Majer, D.; Tojnko S. & Vršič S. (2010). *Smernice za strokovno utemeljeno gnojenje = Guidelines for professionally justified fertilisation*. Ministry of Agriculture, Forestry and Food of Republic of Slovenia, Ljubljana

Montana Department of Environmental Quality (2005). *Flathead Basin Program, quality assurance project plane (QAPP).* Land and Water Quality Consulting/PBS&J, Montana

Moriasi, D.N.; Arnold, J.G.; Van Liew, M.W.; Bingner, R.L.; Harmel, R.D. & Veith, T.L. (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Transactions of the ASABE*, Vol.50, No.3, pp. 885–900

Nash, J. & Sutcliffe, J. (1970). River flow forecasting through conceptual models: I. A discussion of principles. *Journal of Hydrology*, Vol.10, pp. 374–387

Neitsch, S.L.; Arnold, J.G.; Kiniry, J.R. & Williams, J.R. (2005). *Soil and water assessment tool theoretical documentation – Version 2005*. Texas Agricultural Experiment Station, Blackland Research Center, Agricultural Research Service, Grassland, Soil and Water Research Laboratory, Texas, Temple

Pedosphere (2009). Soil Texture Triangle Hydraulic Properties Calculator, 21. July 2010, Available from http://www.pedosphere.com/

Purkey, D.R.; Huber-Lee, A.; Yates, D.N.; Hanemann, M. & Herrod-Julius, S. (2007). Integrating a climate change assessment tool into stakeholder-driven water management decision-making processes in California. *Water Resources Management,* Vol.21, pp. 315–329

Ramos, M.C. & Martinez-Casasnovas, J.A. (2006). Nutrient losses by runoff in vineyards of the Mediterranean Alt Penede`s region (NE Spain). *Agriculture, Ecosystems and Environment*, Vol.113, pp. 356–363

Sardans, J. & Penuelas, J. (2004). Increasing drought decreases phosphorus availability in an evergreen Mediterranean forest. *Plant and Soil*, Vol.267, pp. 367–377

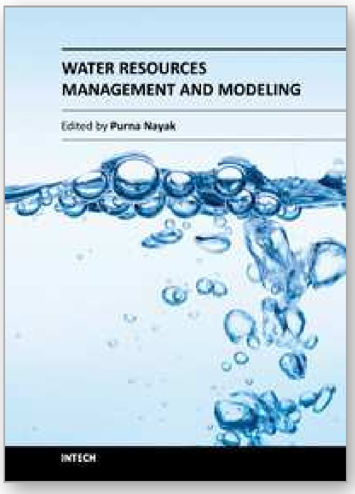
Saxton, K.E.; Rawls, W.J.; Romberger, J.S. & Papendick, R.I. (1986). Estimating generalized soil-water characteristics from texture. *Soil Science Society of America Journal*, Vol.50, No.4, pp. 1031–1036

van Griensven, A.; Meixner, T.; Grunwald, S.; Bishop, T.; Di Luzio, M. & Srinivasan, R. (2006). A global sensitivity analysis tool for the parameters of multi-variable catchment models. *Journal of Hydrology*, Vol.324, pp. 10–23

Volk, M.; Liersch, S. & Schmidt, G. (2009). Towards the implementation of the European Water Framework Directive? Lessons learned from water quality simulations in an agricultural watershed. *Land Use Policy*, Vol.26, pp. 580–588

Wilby, R.L.; Orr, H.G.; Hedger, M.; Forrow, D. & Blackmore, M. (2006). Risks posed by climate change to the delivery of Water Framework Directive objectives in the UK. *Environment International*, Vol.32, pp. 1043–1055

Xu, Z.X.; Zhao, F.F. & Li, J.Y. (2009). Response of streamflow to climate change in the headwater catchment of the Yellow River basin. *Quaternary International*, Vol.208, pp. 62–75



Water Resources Management and Modeling

Edited by Dr. Purna Nayak

ISBN 978-953-51-0246-5

Hard cover, 310 pages

Publisher InTech

Published online 21, March, 2012

Published in print edition March, 2012

Hydrology is the science that deals with the processes governing the depletion and replenishment of water resources of the earth's land areas. The purpose of this book is to put together recent developments on hydrology and water resources engineering. First section covers surface water modeling and second section deals with groundwater modeling. The aim of this book is to focus attention on the management of surface water and groundwater resources. Meeting the challenges and the impact of climate change on water resources is also discussed in the book. Most chapters give insights into the interpretation of field information, development of models, the use of computational models based on analytical and numerical techniques, assessment of model performance and the use of these models for predictive purposes. It is written for the practicing professionals and students, mathematical modelers, hydrogeologists and water resources specialists.

INTECH
open science | open minds

InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821