*Water Quality: Current Trends and Expected Climate Change Impacts* (Proceedings of symposium H04 held during IUGG2011 in Melbourne, Australia, July 2011) (IAHS Publ. 348, 2011). 

# Modelling of the climate change effects on nitrogen loads in the Jizera catchment, Czech Republic

**MARTA MARTÍNKOVÁ[1], VALENTINA KRYSANOVA[2], CORNELIA HESSE[2], MARTIN HANEL[1] & ŠÁRKA BLAŽKOVÁ[1]**

1 *T. G. Masaryk Water Research Institute, Podbabská 30/2582, Praha 6, Czech Republic*
marta_martinkova@vuv.cz

2 *Potsdam Institute for Climate Impact Research, PO Box 601203, Telegrafenberg, Potsdam, Germany*

**Abstract** The consequences of climate change for water quality are significant and are expected to heavily influence water resources management. Here, water quality modelling was done in order to evaluate the impact of climate change on nitrogen loads in the Jizera catchment. The Jizera catchment is of high importance for drinking water supply. We have used the eco-hydrological model SWIM (Soil and Water Integrated Model), which simulates water and nutrient fluxes in soil and vegetation, as well as transport of water and nutrients to and within the river network. The influence of climate change on nitrogen loads in the Jizera catchment was assessed here by using bias-corrected outputs of two dynamic regional climate models (RCMs). The two RCMs show a common trend of higher future total and summer discharge. However, the SWIM modelling results differ in terms of nitrate nitrogen load and its seasonality, between the two RCMs and among the modelled future periods. The uncertainty in the modelling results is caused mainly by differences in the regional climate models.

**Key words** water quality; climate change; nitrogen; regional climate models; uncertainty

## INTRODUCTION

Water quality models can provide valuable support for the assessment and the analysis of pollution loads in river basins, as well as information about potential future changes in water quality under climate change while using the outputs of climate change models. Water quality models are very diverse, from statistical and conceptual models on one hand to process-based and physically-based models on the other. Regional climate models (RCMs) forced by global climate models (GCMs) are usually used for assessment of the climate change impact on water quality in meso-scale basins.

Many sources of uncertainty exist when modelling the climate change impact on water quality (e.g. input data, parameters of model, model structure, and the GCM, RCM and emission scenarios used). One of the possible ways of dealing with uncertainty is to focus on one of its sources at the time. In our study, we have used the eco-hydrological process-based model SWIM (Soil and Water Integrated Model) for assessment of the climate change impact on nitrogen loads. SWIM has already been successfully implemented for various types of catchments from meso-scale to macro-scale, but mainly for lowland meso-scale catchments (Hattermann *et al.*, 2006; Hesse *et al.*, 2008) and macro-scale basins (Huang *et al.*, 2009). We have already applied the SWIM model in order to analyse pollution loads and to assess the potential climate change impact on water quality in the meso-scale catchment of the Jizera River in the Czech Republic, Europe (Martínková *et al.*, 2011).

In this particular study, we focused on comparison of two RCMs forced by the same GCM, with the same localisation of grid points and processed with the same bias-correction method. The aim was to evaluate the uncertainty in modelling of climate-change impact on nitrogen loads originated in differences between the RCMs. We used the REMO and RACMO RCMs from the ENSEMBLES data set (http://ensemblesrt3.dmi.dk/).

## DATA AND METHODS

The Jizera catchment (2180 km$^2$) is a part of the Elbe Basin and is located in the Czech Republic. The River Jizera is 185 km long and drains into the River Elbe. Altitude of the catchment varies between 168 and 1434 m a.s.l. Both point sources and diffuse sources of nitrogen are important.

To set-up the model for the Jizera catchment, four raster maps characterizing the study area: a digital elevation model, a soil map, a land-use map and a sub-catchment map (203 sub-catchments), were used. All maps had the same resolution of 100 × 100 m. Climate data (maximum, mean and minimum temperature, precipitation, solar radiation and air humidity) were interpolated to the centroids of every sub-catchment by the inverse distance method using 10 climate stations in and around the Jizera catchment. Locations of the climate stations are given in Fig. 1.

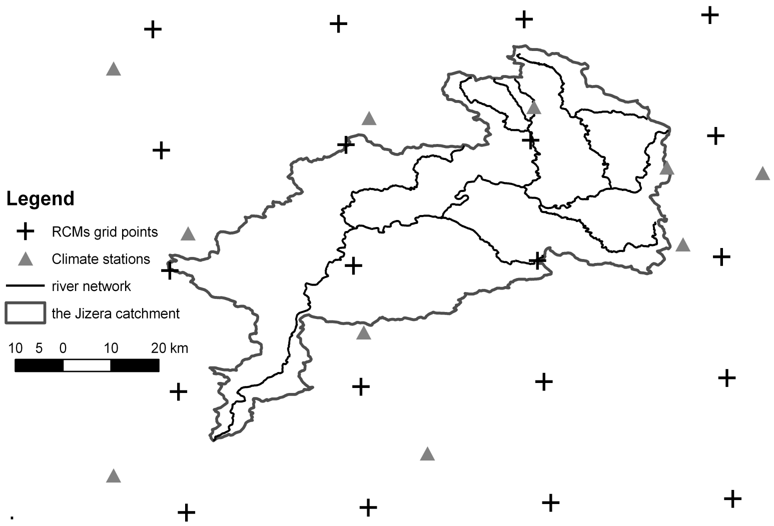


**Fig. 1** Map showing the Jizera catchment and location of climate stations and grid points.

The Czech Hydrometeorological Institute provided the daily discharge data and monthly measurements of nitrate nitrogen at the outlet of the catchment for model calibration. We used the linear interpolation method for calculating the daily nitrogen load at the catchment outlet. We implemented the data on location and output of point sources (144 sewage treatment plants) in the SWIM model. These data were added to the daily nutrient amount of the corresponding sub-basins. Fertilization data typical for the catchment were also used in the model (Martínková *et al.*, 2011).

## Regional climate models

Here we used the ENSEMBLES data set (http://ensemblesrt3.dmi.dk/), and specifically the outputs of the REMO and RACMO transient experiments 1951–2100 for emission scenario A1B, driven by global climate model ECHAM5-r3 with a horizontal resolution of 25 × 25 km. REMO (REgional MOdel) was developed in the Max-Planck Institute for Meteorology in Hamburg, Germany (Jacob, 2001). RACMO was developed mainly at the Royal Netherlands Meteorological Institute (Meijgaard *et al.*, 2008).

The dynamical RCMs in general tend to produce systematic biases (Frei *et al.*, 2003; Christensen *et al.*, 2008). These systematic differences between the observed and simulated data can be corrected by using a bias correction method. Here we used the non-linear correction approach proposed by Leander & Buishand (2007) for adjusting the used RCMs outputs (precipitation, temperature and humidity). The method is based on a general change factor methodology that represents the change from the reference period to the future scenario. Precipitation ($P$), temperature ($T$) and humidity ($H$) were transformed as follows:

$$P_{CORF} = aP_{SIMF}^{b} \tag{1}$$

$$T_{CORF} = a + b(T_{SIMF} - \overline{\overline{T}}_{SIMF}) + \overline{\overline{T}}_{SIMF} \tag{2}$$

$$H_{CORF} = 1 - a(1 - H_{SIMF})^{b} \tag{3}$$

Index $_{CORF}$ denotes a corrected value for the future period, index $_{SIMF}$ denotes a simulated value for future period and $\overline{\overline{T}}_{SIMF}$ denotes average in the equations (1), (2) and (3). The equations depend on two parameters, *a* and *b*. The parameters for each day are estimated using the mean and coefficient of variation. The value of parameter *b* was optimized first for precipitation (equation (4)) and for humidity (equation (5)):

$$cv(P_{OBSR}) = cv(P^{b}_{SIMR}) \tag{4}$$

$$cv(1-H_{OBSR}) = cv[(1-H_{SIMR})^{b}] \tag{5}$$

In equations (4) and (5), *cv* denotes the coefficient of variation.

The value of parameter *a* was calculated using equation (6) in the case of precipitation and after equation (7) in the case of humidity:

$$a = \overline{P_{OBSR}} / \overline{P^{b}_{SIRMR}} \tag{6}$$

$$a = (\overline{1-H_{OBSR}} / \overline{(1-H_{SIMR})^{b}} \tag{7}$$

For temperature, the parameter *a* was derived directly from difference between the means of temperatures after equation (8) and parameter *b* from the ratio of temperatures' standard deviations (*sd*) using equation (9):

$$a = \overline{T}_{OBSR} - \overline{T}_{SIMR} \tag{8}$$

$$b = sd(T_{OBSR}) / sd(T_{SIMR}) \tag{9}$$

Index $_{OBSR}$ denotes observed value for reference period while index $_{SIMR}$ denotes simulated value for reference in the equations (6), (7), (8) and (9). The transformation parameters *a* and *b* for all the values were derived for every day of the year from a time window of 30 days before and 30 days after, from all years of a given period (Leander & Buishand, 2007). Data for each of the climate stations (Fig. 1) was processed individually to be later used as input data for modelling with the SWIM eco-hydrological model; data of RCMs nearest grid points were interpolated to the station locations by using the inverse distance method. The bias correction was processed for three 30-year periods: 2011–2040, 2041–2070 and 2071–2100 while the reference period was 1972–2001. After the bias correction the three 10-years periods (2031–2040, 2061–2070 and 2091–2100) were used for SWIM modelling.

## RESULTS AND DISCUSSION

### Calibration and validation of nitrogen

The calibration and validation of discharge and nitrate nitrogen loads was already successful in a previous study (Martínková *et al.*, 2011). In that study, strong seasonality of discharge and nitrate nitrogen load was observed. The highest monthly mean discharge was observed during April (28 $m^3$ $s^{-1}$) and the lowest from August to October (around 6 $m^3$ $s^{-1}$), while the highest monthly mean nitrate nitrogen loads was observed during winter (12 000 kg in March) and the lowest during summer (2000 kg in August).

### Outputs of RCMs

Here, we estimated differences between the REMO and RACMO RCMs regarding the relative changes of discharge, nitrate nitrogen loads and concentrations between the RCM-modelled future periods and the reference period 1992–2001 in total, for the summer months (April–September) and for the winter months (October–March). All these values are expected to change significantly (Andersen *et al.*, 2006). The results are summarized in Table 1 and Fig. 2.

**Table 1** Percentage change in mean water discharge (Q), nitrate nitrogen loads ($NO_3$-N load) and concentrations ($NO_3$-N conc.).

| | | Q | | $NO_3$-NN-$NO_3$ load | | $NO_3$-N conc. | |
|---|---|---|---|---|---|---|---|
| | | REMO | RACMO | REMO | RACMO | REMO | RACMO |
| 2031–2040 | Total | 8.7% | –0.6% | –13.3% | –5.6% | –23.5% | 0.3% |
| | Summer | 16.1% | 10.7% | 11.3% | 7.9% | –4.1% | 4.2% |
| | Winter | 0.7% | –8.6% | –8.1% | –11.8% | –2.2% | –2.4% |
| 2061–2070 | Total | 22.9% | 40.4% | -3.6% | 5.6% | –31.2% | –23.9% |
| | Summer | 33.4% | 61.0% | 13.2% | 17.9% | –26.6% | –22.4% |
| | Winter | 13.4% | 25.9% | –13.9% | –0.1% | –34.5% | –25.0% |
| 2091–2100 | Total | 8.7% | 27.6% | –13.3% | 1.9% | –23.5% | –20.8% |
| | Summer | –20.3% | 20.0% | –42.1% | 0.2% | 4.8% | –9.0% |
| | Winter | 21.9% | 32.9% | –3.6% | 2.6% | 2.1% | –29.0% |

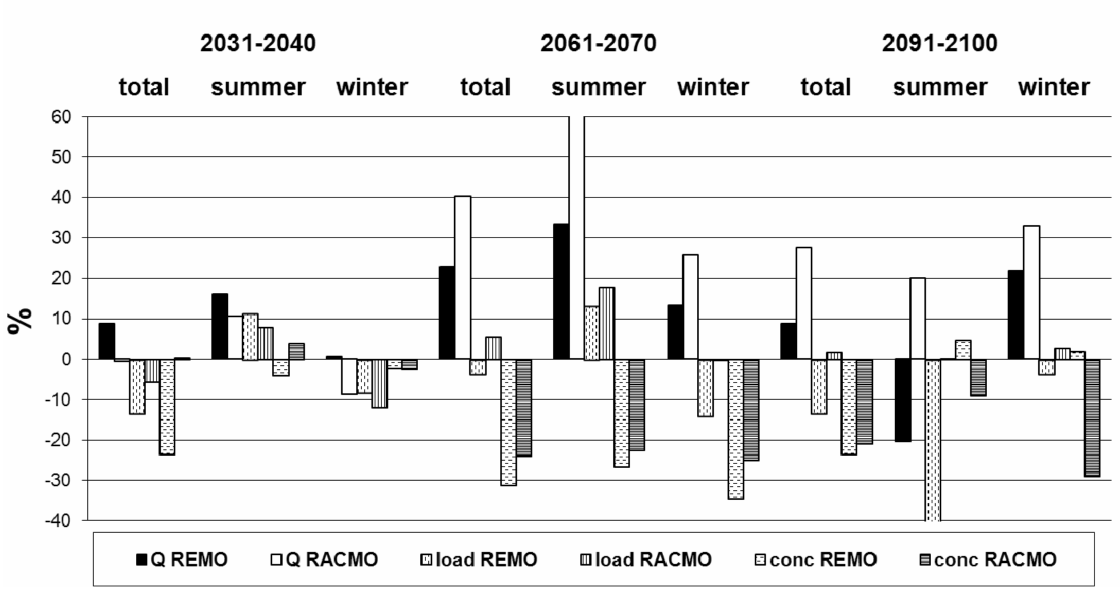


**Fig. 2** Diagram showing the comparison of percentage change of discharge (Q), nitrate nitrogen loads (load) and concentration (conc) between the future periods and the reference period.

The results show that the RCMs differ between each other in predictions of discharge, nitrate nitrogen loads and concentration.

## Changes in discharge and nitrate nitrogen concentrations

Discharge as predicted by RCMs is higher for periods 2061–2070 and 2091–2100, while RCM REMO predicts lower discharge than RCM RACMO. In contrast, discharge for period 2031–2040 are predicted to be higher by RCM REMO and insignificantly lower by RCM RACMO. Discharge predicted by RCMs is higher during summer than winter, only the RCM REMO predicted lower discharge during summer for period 2091–2100. The discharge during winter is higher only for the period 2031–2040; RCM REMO predicts discharge to remain the same and RCM RACMO predicts an 8.6% lower discharge.

The concentrations generally depend on discharge: higher discharge is associated with lower concentration and *vice versa* (Table 1 and Fig. 2). The only exception is concentration during summer for the period 2031–2041, as modelled by RCM RACMO. This high concentration may be caused by a combination of high temperatures and high evaporation coupled with extreme precipitation and consequent higher leaching of nitrogen.

### Changes in nitrate nitrogen loads

The changes in nitrate nitrogen loads are more complex and depend not only on discharges, but also on the seasonal dynamics of nitrogen. The changes in nitrate nitrogen loads in total, as projected by RCM REMO, are inversely proportional to discharge for all the modelled future periods of 2031–2040 and 2091–2100. Higher discharge during winter results in a lower load. The nitrogen loads in total as projected by RCM RACMO are lower for period 2031–2040, which is caused by low discharge during the winters of this period. The loads are higher for periods 2061–2070 and 2091–2100 because of high discharge during summer. Both the RCMs predict higher nitrogen loads during the summers of the periods of 2031–2040 and 2061–2070 than for those of the reference period in connection with high discharge and possibly more intensive leaching of nitrate during the episodes of high precipitation. Nevertheless, the RCM REMO predicts lower summer nitrate nitrogen loads for the period of 2091–2100 than for the reference period, and the RCM RACMO predicts almost unchanged nitrate nitrogen loads despite the high discharge (Fig. 2). The effect of more intensive nitrogen leaching is probably not significant because of a low occurrence of intensive rains or other factors that influence the transport of nitrogen to the river in this period. Consequently, the nitrate nitrogen loads are supposed to predominantly originate from relatively stable pollution sources (e.g. point sources).

Interestingly, the two RCMs predict similar winter nitrate-nitrogen loads for the period of 2031–2040 while they differ significantly in the predicted winter nitrate-nitrogen loads for the periods of 2061–2070 and 2091–2100 (see Fig. 2). RCM REMO predicts lower nitrate-nitrogen loads during the winters of all the future periods than during the winters of the reference period, despite the changes in discharge, which is caused by absence of nitrogen sources that are active during summer. The RCM RACMO predicts lower nitrate nitrogen loads during the winters of the period 2031–2040 and slightly higher loads for the periods 2061–2070 and 2091–2100. The uncertainty in modelling results is caused mainly by differences in RCMs. Other sources of uncertainty (the bias correction method used, structure of hydrological model, changes in nitrogen sources and sinks) were not studied here, but may be significant.

## CONCLUSIONS

In the present study we evaluated climate change impacts on nitrate nitrogen load in river water. We focused on the comparison of two dynamical RCMs outputs: REMO and RACMO of ENSEMBLES data set. We used the SWIM model for the modelling of discharge, nitrate nitrogen loads and concentrations. The SWIM results highlight the large uncertainty while using RCMs for modelling of water quality in catchments. These two RCMs show a common trend of both higher total discharge and higher summer discharge in the future. However, the SWIM modelling results from the two RCMs differ in modelled nitrate nitrogen loads with respect to seasonality and among the modelled future periods. The uncertainty in modelling results is caused mainly by differences in the regional climate models.

**Acknowledgements** The study was performed in the Project SP/2e7/229/07 of the Ministry of Environment of the Czech Republic. The ENSEMBLES data used in this work was funded by the EU FP6 Integrated Project ENSEMBLES (contract no. 505539) whose support is gratefully acknowledged.

## REFERENCES

Andersen, H. E., Kronvang, B., Larsen, S. E., Hoffmann, C. C., Jensen, T. S. & Rasmussen, E. K. (2006) Climate-change impacts on hydrology and nutrients in a Danish lowland river basin. *Sci. Total Environ.* **365**, 223–237.

Christensen, J. H., Boberg, F., Christensen, O. B. & Lucas-Picher, P. (2008) On the need for bias correction of regional climate change projections of temperature and precipitation. *Geophys. Res. Lett.* **35**, L20709. DOI:10.1029/2008GL035694.

Frei, C., Christensen, J. H., De´que´, M., Jacob, D., Jones, R. G. & Vidale, P. L. (2003) Daily precipitation statistics in regional climate models: evaluation and intercomparison for the European Alps. *J. Geophys. Res.* **108** (D3), 4124 doi:10.1029/2002JD002287.

Hattermann, F. F., Krysanova, V., Habeck, A. & Bronstert, A. (2006) Integrating wetlands and riparian zones in river catchment modeling. *Ecological Modelling* **199**, 379–392.

Hesse, C., Krysanova, V., Päzolt, J. & Hattermann, F. F. (2008) Eco-hydrological modeling in a highly regulated lowland catchment to find measures for improving water quality. *Ecological Modelling* **218**, 135–148.

Huang, S., Hesse, C., Krysanova, V. & Hattermann, F. (2009) From meso- to macro-scale dynamic water quality modelling for the assessment of land use change scenarios. *Ecological Modelling* **220**, 2543–2558.

Jacob, D. (2001) A note to the simulation of the annual and inter-annual variability of the water budget over the Baltic Sea drainage basin. *Met. & Atmos Phys.* **77**, 61–73.

Leander, R. & Buishand, T. A. (2007) Resampling of regional climate model output for the simulation of extreme river flows. *J. Hydrol.* **332**, 487–496.

Martínková, M., Hesse, C., Krysanova, V., Vetter, T. & Hanel, M. (2011) Potential impact of climate change on water quality in the Jizera catchment (Czech Republic). *Physics and Chemistry of the Earth* (submitted).