Development of a European modeling approach of nutrients transfer in terrestrial and aquatic continuums: Setting-up the methodology on the Seine and Danube watersheds

Vers une modélisation des transferts de nutriments dans les continuums terrestres et aquatiques à l'échelle européenne. Application aux bassins de la Seine et du Danube

Vincent Thieu [1]; Liliana Pagliero [1]; Marie Silvestre [2]; Gilles Billen [2]; Fayçal Bouraoui [1]; Josette Garnier [2]

[1] European Commission - Institute for Environment and Sustainability - Rural, Water and Ecosystem Resources Unit - Joint Research Centre - Via Fermi, TP 460, 21027 Ispra (VA) – Italy (corresponding author: vincent.thieu@jrc.ec.europa.eu). [2] CNRS/UPMC UMR7619 Sisyphe – 4 place Jussieu 75005 Paris - France

RÉSUMÉ

L'ampleur des modifications du fonctionnement biogéochimique des systèmes aquatiques (contamination azotée généralisée des eaux douces, eutrophisation et anoxie des zones côtières,…) impose une modélisation à grande échelle du lien entre le développement des sociétés humaines et le fonctionnement des hydrosystèmes depuis les têtes de bassins jusqu'aux zones côtière. A l'échelle de l'Europe, le développement d'une base d'informations environnementales homogène permet un couplage on-line des modèles SWAT et Riverstrahler. Ces deux modèles à base physiques sont utilisés pour décrire les transferts des nutriments respectivement dans les parties terrestres (SWAT) et aquatiques (Riverstrahler). En s'appuyant sur les bases de données standardisées, et de part sa conception générique, le couplage des modèles est parfaitement transposable à l'ensemble des bassins Européen. Une première application est présentée à l'échelle des bassins de la Seine et du Danube.

ABSTRACT

The extent of changes in the biogeochemical functioning of aquatic systems (e.g. generalized contamination of freshwater by nitrogen, worldwide eutrophication and anoxia in coastal areas) required to extend to a larger scale the modelling of hydrosystems and its relationship with the development of human societies (globalized). At the European scale, the development of a harmonized environmental database has enabled the coupling of the SWAT and Riverstrahler models. These two models are physically based and used to describe the transfer of nutrients respectively in the terrestrial (SWAT) and aquatic (Riverstrahler) parts of the watersheds.

Based on the standardized databases, and because of its generic design, the coupling of models is perfectly transposable to all European basins. A first application is presented on the scale of the Seine and the Danube river basins

KEYWORDS

European scale, Nutrients, Riverstrahler, SWAT.

1 INTRODUCTION

Nutrient fluxes exported from watersheds exposed to important anthropogenic pressures, are responsible for the eutrophication of coastal areas, and recent works have reported the widespread of these symptoms at the global scale. The “Land-Ocean” continuum stretches out alongside river systems, and as a consequence, river-biogeochemistry needs to be up-scaled to continental scope. At present, modeling tools available at such a scale are mainly (semi-)empirical and do not represent the physics and the variability of processes governing the functioning of aquatic ecosystems. To of our knowledge, the modeling work conducted jointly by the JRC (European Commission) and the UMR Sisyphe (CNRS/UPMC) is the first attempt to provide a pan-European modeling of nutrient cycling in watersheds based on a detailed description of the processes occurring from headwaters down to coastal areas.

Two existing models (Riverstrahler and SWAT) are coupled for this purpose. The formalism of each model and the principle of this coupling will be introduced as a first part of this paper. Then, the paper highlights the development of a common modelling data framework for the continental Europe as a prerequisite of this modelling exercise. Finally, a first application to the Seine and the Danube river basins is presented.

2 METHODS:

2.1 From the microscope to the ecological functioning of large rivers

In agreement with the river continuum concept, the ecological Riverstrahler model (Garnier et al., 1995) takes into account the physiology of algal developments and simulates the biogeochemical cycles of carbon, nitrogen, phosphorus and silica in an entire drainage network. Most of the processes important in the transformation, elimination, and/or immobilization of nutrients during their transfer within the network of rivers and streams are explicitly calculated. Considering that the same processes operate in all aquatic ecosystems and obey to the same microscopic kinetics, the Riverstrahler approach also assumes that the singular functioning of aquatic ecosystems is directly related to the variety of constraints applied to the aquatic continuum. Thereby, an accurate description of these constraints is the key to understand the functioning of any hydrosystem (Thieu et al., 2009).

2.2 Integrating landscape interfaces to aquatic continuums

An attempt to expand the Riverstrahler model as a generic tool for all European rivers is solely restricted to our capacity to provide an accurate description of all macroscopic pressures applied to these systems. Among the collection of watersheds models available, the Soil Water Assessment Tool (SWAT, Neitsch et al., 2005) is one of the few physically based approaches describing processes responsible for the transfer of nutrients from soil to water with an explicit representation of plants growths and impacts of agricultural management practices. Conceptually, SWAT simulations allow a clear separation of the land phase and the aquatic routing processes.

A specific module has been developed to extract water and nutrient fluxes simulated by SWAT at the interface between the terrestrial part of the watersheds and the drainage network, and then automatically generate inputs for the Riverstrahler model. Such on-line coupling is based on the use of the elementary watershed as a shared computing unit between the two models. SWAT simulations are extracted at a daily time step, while Riverstrahler simulations are aggregated to 10-days with a kilometric resolution along all river streams.

3 RESULTS AND DISCUSSION

3.1 Setting up a common modelling data framework for continental Europe

To support the use of SWAT and Riverstrahler models environmental databases available at EU-scale have been harmonized, to gather information related to climate, landuse, nutrient pressure (fertilizers applications, point sources emissions, erosion of particles) and river basin morphology. Such development is required by the complexity of the two physically based approaches and aims at

supplying the exchange of information between the two models using unified spatial features. The challenge lies in enabling a standard implementation of the coupled SWAT-Riverstrahler approach to any river basin in Europe.

3.2 First application of the SWAT-Riverstrahler models to the Seine and the Danube river basins.

The Seine and the Danube watersheds together offer a text book example of river basins gathering a wide range of natural and anthropogenic constraints. The Danube river basin is the second largest river basin in Europe, covering ca. 803,000 km2 and 14 countries. Due to its large extension and diverse topography, it shows an important climatic variability. Comparatively, the Seine river area is much affected by human activities with the huge Paris agglomeration (10 millions inhabitants) and also one the most productive agricultural area in Europe.

The performance of the coupled SWAT-Riverstrahler models is assessed for both watersheds over the period 1995 – 2005. A detailed budget of nutrients (N and P) transfers and transformation calculated by the coupled model is provided, highlighting the relevance of such integrated tool to depict the fate of nutrient on the basis of a comprehensive apportionment of all ecological processes.

4 CONCLUSION AND PERSPECTIVES

This work enabled to set up the methodology for coupling on-line a terrestrial biogeochemical model and an aquatic ecological model. Further developments include for example a better integration of the terrestrial silica cycle. Nevertheless, this suit of models is now operational and their implementation is fully reproducible for every basin in Europe. Finally, the aim of such large scale modeling work is also to enable prospective analyses to evaluate the impacts of global trends and changes in human activities. The coupled SWAT-Riverstrahler is also expected to support the assessment of future environmental directives in Europe.

LIST OF REFERENCES

Garnier J., Billen G. & Coste M. (1995). Seasonnal succession of diatoms and Chlorophyceae in the drainage network of the river Seine: Observations and modelling. Limnol. Oceanogr. 40: 750-765.

Neitsch, S. L., Arnold, J. G., Kiniry, J. R., and Williams, J. R. (2005). Soil and Water Assessment Tool (SWAT), Theoretical Documentation. Blackland Research Center, Grassland. Soil and Water Research Laboratory, Agricultural Research Service. Temple, TX.

Thieu V., Billen G., Garnier J. (2009). Nutrient transfer in three contrasting NW European watersheds: the Seine, Somme, and Scheldt Rivers. A comparative application of the Seneque/Riverstrahler model, Water Research, 43(6):1740- 1754