Modeling in-stream biogeochemical processes at catchment scale: Coupling SWAT and RIVE models

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Highlights

- SWAT and RIVE models were coupled to enhance the modeling of in-stream biogeochemical processes in SWAT.
- An epilithic biofilm model was added to the coupled model.
- The coupled model was validated on a 89 km section of the Garonne watershed.
- Annual and seasonal interannual budgets for nutrients and organic matter were established.

Abstract

The representation of biogeochemical in-stream processes is complex and requires the use of models to understand the factors controlling the transfer of contaminants at the scale of a watershed. The biogeochemical model RIVE was implemented into SWAT model and used, instead of current QUAL2E subroutine, to calculate biogeochemical in-stream processes. The coupled model was applied on a 89 km section of the Garonne watershed (France) downstream of Toulouse city, for the 2000-2010 period, with a daily time step. An epilithic biofilm equation was added to represent the algae communities in this river, dominated by drifted benthic diatoms. The model matches the observed data for the major water-quality variables. Nitrogen, phosphorus, silica, and organic suspended matter dominant processes were assessed. The goal of coupling RIVE to SWAT model was to improve the biogeochemical representation of the river's in-stream ecological processes linked to C, N, P, Si elementsand dissolved oxyxgen with minimal calibration.

Keywords

Water quality, model coupling, nutrient budget

1. Introduction

SWAT (Soil and Water Assessment Tool, Arnold et al., 1998) is one of the most applied hydro-agro-ecological models in the world, having been successfully implemented on a large variety of watersheds (Gassman et al., 2007, 2014; Krysanova and Arnold, 2008; Krysanova and White, 2015; Francesconi et al., 2016). This physically-based and semi-distributed agro-hydrological model was developed to predict the impacts of land use, land management practices and climate change on water quantity and quality. It simulates the transfer of biogenic elements from land to river at the watershed scale. The in-stream biogeochemical processes are simulated by a modified version of the QUAL2E model (Brown and Barnwell, 1987), which takes into account the main transformations in nitrogen and phosphorus cycles only. Activation of this module is optional.

SWAT, with QUAL2E module activated, has demonstrated good performances in several studies, but mainly at monthly or annual scales (Gassman et al., 2007). However, other authors reported poor to moderate performances in simulating nutrient loads (Grunwald and Qi, 2006) or a need to refine the in-stream processes routine (White et al., 2014). The mass balance is not closed, the sedimentation and diffusion of nutrients from the streambed being disconnected. Migliaccio et al. (2007) found no enhancement in nutrient predictions when activating QUAL2E in SWAT instead of deactivating in-stream process simulation. Moreover, the numerical method employed to solve the QUAL2E differential equations in SWAT can lead to instabilities and solution inconsistencies, particularly in reaches with extended residence times (Woldegiorgis et al., 2017). Femeena et al. (2020) noted high daily fluctuations in dissolved oxygen simulations, whereas the ability to simulate dissolved oxygen concentrations was critical for water quality modeling, due to their influence on nitrogen and phosphorus cycles. Regarding phytoplankton, the module represents a total algae biomass, without considering the diverse physiological properties (growth, mortality, nutrients uptake rates) of different algal groups, nor the influence of silica on algal development. Furthermore, the module does not represent epilithic biofilm and is therefore not adequate for the systems where it is dominant (White et al., 2014). Regarding the nitrogen cycle, denitrification remains unaccounted for, while benthic denitrification is a key process for nitrogen removal in streams (Xia et al., 2018). Finally, the QUAL2E module requires a systematic calibration, which is a challenging step for achieving robust water quality simulations (Gassman et al., 2007; Houser and Hauck, 2002).

To address SWAT in-stream biogeochemical processes representation gaps, external couplings were made, principally for better assessing nutrient transformations and algal growth in water bodies (coupling with WASP (Narasimhan et al., 2010) or CE-QUAL-W2 (Debele et al., 2008)), or to simulate turbidity propagation in streams (coupling with CE-Qual-Riv1 (Noh et al., 2013)). In terms of internal couplings, Pyo et al., (2019) modified the QUAL2E algal module with CE-QUAL-W2 equations to simulate in-stream dynamics of three algal groups while Kim and Shin (2011) modified the QUAL2E module to simulate algal growth kinetics in detail to improve the accuracy of internal organic matter and bottle BOD5 simulation. These mentioned studies focused on one aspect of water quality (algae, organic matter).To our knowledge refinement was made on both phytoplankton and organic carbon simulations, as well as on processes occurring in the benthic zone, in order to comprehensively describe the fate of nitrogen and phosphorus in streams. Further, Femeena et al. (2020) integrated a new solute transport model developed based on OTIS (One-dimensional Transport with Inflow and Storage) to account for advection, dispersion, transient storage exchange and calculate at sub-daily scale and smaller segments. However, the computational time was 60 times longer, so they recommended to use the model only for small time period simulations. In ESWAT (Van Griensven and Bauwens, 2003), the riverbed mass balance was closed and the numerical scheme was modified with the use of an hourly time step. The mixing of the inflow occurred after applying concentration transformation to the channel's initial concentration at the beginning of the time step. Nonetheless, instabilities were still observed, as noted by **these authors**. The recent quasi-analytical solution proposed by Woldegiorgis et al. (2017) for QUAL2E in SWAT has provided stable and consistent solutions **in our own modeling**.

RIVE model is a mechanistic model that describes in-stream ecological and biogeochemical processes. It was developed to understand the dynamics of nutrients, the trophic chain in the river systems, and the development of three types of algae within rivers. It was implemented in several models: Riverstrahler (Billen et al., 1994; Garnier et al., 1995), ProSe (Even et al., 1998), pyNuts-Riverstrahler (Thieu et al., 2022), and QUAL-NET (Minaudo et al., 2018). It was developed and mainly applied on the Seine River, and successfully applied for a variety of watersheds such as Somme, Scheldt (Thieu et al., 2009), Danube (Garnier et al., 2002), Loire (Garnier et al., 2018a), Red River (Le et al., 2010), Kalix (Sferratore et al., 2008) and on the Garonne major tributary, the Lot River (Garnier et al., 2018b). RIVE model considers the physiology of algal developments and simulates biogeochemical cycles of carbon, nitrogen, phosphorus and silica along hydrographic networks, including interactions between the water column and the benthic zone. RIVE's equations and parameters were determined based on experiments and directly linked to easily measurable environmental variables. RIVE does not require calibration, although the narrouw range of parameter determination can be possibly explored in case of strong disagreement with observed variables . Currently, RIVE model is undergoing revision and unification by the Metis Lab developers' team and will soon be made accessible to the scientific community through a collaborative platform at (https://gitlab.in2p3.fr/rive).

RIVE model was integrated into SWAT, and a section of the Garonne watershed in France was selected for model testing and validation. This choice was based on the availability of numerous studies and measurements, providing all the necessary data for analysis. The section, extending from Toulouse to the Malause reservoir, receives the urban effluents of Toulouse city and is therefore an appropriate site to evaluate their impact on water quality. As the Garonne River is a system dominated by epilithic biofilm (Améziane et al., 2003), an epilithic biofilm module was also added.

The objectives of this study were (i) to model detailed in-stream ecological processes by integrating and validating RIVE model into SWAT, (ii) to assess the dynamic of the dominant nutrient cycles and particulate organic matter in a section of the Garonne River.

2. Material and methods

2.1.1. Models overview

SWAT model

SWAT calculations are conducted on a daily time step, and the outputs can be generated on a daily, monthly, or yearly basis. The watershed is spatially discretized into sub-basins, which are divided into hydrological response units (HRU), a unique combination of slope, soil type and land use. Water, sediment, and nutrients are calculated at the HRU scale, aggregated at the sub-basin level, and routed through the hydrographic network to the outlet. The variables and processes in SWAT land phase are summarized in Table 1. Carbon cycle is only calculated in the land phase. In the streams, the QUAL2E module includes eight variables: algae (as chlorophyll a), dissolved oxygen, carbonaceous oxygen demand, organic nitrogen, ammonium, nitrite, nitrate, and soluble and organic phosphorus. Further details can be found in Neitsch et al. (2011).

Table 1: SWAT land processes

Variables	Land processes	Transfers to reach
Water	Evapotranspiration, infiltration, runoff, plant uptake, percolation, lateral flow, groundwater flow	Runoff, lateral flow, groundwater flow
Nitrogen (organic, nitrate, nitrite, ammonia)	Plant uptake, nitrification, denitrification, ammonia volatilization, atmospheric deposition and fixation, mineralization, immobilization, nitrate leaching, nitrate loss in shallow aquifer	Nitrate in runoff, lateral flow and groundwater flow, organic nitrogen in runoff
Phosphorus (organic, mineral)	Mineralization, immobilization, sorption, leaching	Organic and soluble P in runoff, mineral P attached to sediment in runoff, soluble P in groundwater flow
Carbon	Static content or decomposition, humification	
Sediment	Water erosion	Total suspended sediment load

RIVE model

RIVE model performs calculations using time steps ranging from six minutes to one hour. In the version used, 35 state variables are defined: nutrients (nitrate, ammonium, nitrite, total inorganic phosphorus, orthophosphates, dissolved and biogenic silica), suspended matter, biological compartments (three kind of phytoplankton, two of zooplankton, two of heterotrophic bacteria, two of nitrifying bacteria, two of fecal bacteria), seven compartments of non-living organic matter (particulate and dissolved, with three classes of biodegradability each, and small organic substrate directly uptaken), dissolved oxygen and nitrous oxide for the water column; and for the benthos, three compartments of organic matter (classes of biodegradability) and deposited matter, silica, inorganic phosphorus and fecal bacteria. The model accounts for the filtration by lamellibranchs. Their impact on phytoplankton dynamics is represented as a constraint, their complex life cycle is not modeled. The processes represented within the model are summarized in Table 2. Benthic nutrient fluxes are calculated according to the new simplified algorithm (Billen et al., 2015).

Table 2: Processes represented in RIVE model, based on Garnier et al. (2002), Ruelland et al. (2007a)

Variables	Processes
Suspended and deposited sediment	Sedimentation, erosion

Phytoplankton	Photosynthesis, growth, respiration, lysis, sedimentation
Zooplankton	Grazing, growth, respiration, mortality
Heterotrophic bacteria	Organic matter degradation, growth, mortality, sedimentation
Non-living organic matter	Hydrolysis, sedimentation, compaction, erosion, phytoplankton excretion
Dissolved oxygen	Photosynthesis, respiration, nitrification, benthic consumption
Nitrogen	Phytoplankton and heterotrophic bacteria uptake, ammonification, nitrification, water column and benthic denitrification and nitrous oxide production, benthic remineralization, nitrous oxide ventilation
Nitrifying bacteria	Growth, mortality, sedimentation
Phosphorus	Phytoplankton uptake, adsorption and desorption, benthic remineralization, zooplankton and heterotrophic bacteria mineralization, erosion, sedimentation, compaction
Silica	Diatoms uptake, dissolution, water-sediment interface flux, sedimentation, erosion, compaction
Fecal bacteria	Mortality, sedimentation

Epilithic biofilm model

The Boulêtreau et al. (2006)'s epilithic biofilm model added was adapted from Uehlinger et al. (1996) and precisely developed on the Garonne watershed. We opted for the three-parameter model, which accounts for net biomass growth restricted by biomass thickness and a detachment term that varies in proportion to the mean daily discharge Q.The detachment coefficient (*cdet*) was set to 0.0016 s m^{-3} d^{-1}, the maximum specific growth rate (μmax) to 7.84 d^{-1}, and the inverse half-saturation constant ($k_{inv,B}$) to 3.8 g ash-free dry mass $[AFDM]^{-1}$ m^2. *B* is the epilithic biomass (g AFDM m^{-2}) and *B0* the minimal biomass (g AFDM m^{-2}).

$$\frac{dB}{dt} = \mu max \times B \times \frac{1}{1+k_{inv,B} \times B} - cdet \times Q \times (B - B0) \qquad (3)$$

The detachment term gives the drifted biofilm biomass. To convert the detached biomass from gAFDM.m^{-2} to mgC.l^{-1}, we utilized SWAT-estimated reach length and width, with the latter adjusted due to overestimation. We applied a coefficient of 0.4 corresponding to the surface of riffles in this section of the Garonne according to Simeoni-Sauvage (1999), where biofilm develops. The autotrophic index (i.e., ratio AFDM/chlorophyll a) was set to 100, mean value calculated on Garonne epilithic biofilm data. RIVE model diatoms equations and parameters were applied to drifted biofilm, as epilithic algal communities are dominated by this algal group (Eulin and Le Cohu, 1998).

Nitrate, nitrite, and ammonia exchanges between the water column and the biofilm were set according to Teissier et al. (2007) daily budgets determined on the Garonne in its middle course, with a threshold of 23 g AFDM m^{-2} between photoautotrophy and heterotrophy.

Coupled SWAT-RIVE model

We used the version SWAT2012 VER 2016/Rev 664. The coupling with RIVE model is internal. A subroutine containing RIVE equations was integrated into SWAT. This subroutine is called instead of QUAL2E when the parameter IWQ (in .bsn file) is set to 3 (IWQ 0 = do not use QUAL2E, 1 = use QUAL2E, 3 = use RIVE). The historical version of the RIVE code (https://gitlab.in2p3.fr/rive/original_vb_code), initially in Visual Basic, was used and transcribed into Fortran 90 language to be integrated into SWAT model. The coupled model space scale (river reach) and time scale (daily) are the same as SWAT. The RIVE module has been implemented following the structure of the QUAL2E module included in SWAT, with a small modification. The module is called by reach (as defined in SWAT, one per sub-basin) and once a day, but we added an hourly loop to calculate variations and update concentrations every hour during the travel time within the reach. This method prevents instabilities that could occur in reaches with high residence times.

SWAT and RIVE connection

The land phase is simulated by SWAT, which calculates water fluxes, nutrients cycles and suspended sediment erosion, subsequently determining the resulting loads to the reach (Figure 1). Water fluxes are simulated by the SWAT subroutine, while nutrient transformations are handled by the RIVE subroutine. Both models initially calculate processes related to suspended sediments. SWAT computes the deposition and degradation of total suspended sediments (TSS) in the channel whileRIVE computes total suspended sediments deposition and degradation, along with additional processes for organic suspended sediments and phosphates adsorption-desorption (see Table 2). To avoid double-counting of TSS deposition and degradation, the choice was made to keep the in-stream sediment subroutine of SWAT. Organic suspended sediments processes were simulated by RIVE. Silica and organic carbon diffuse inputs are required by RIVE but not calculated by SWAT. Consequently, dissolved silica diffuse inputs were determined with lithology, giving a constant concentration in surface runoff and groundwater flow by rock types (Meybeck, 1986), values used for the application of Riverstrahler on the Lot River, Garonne tributary (Garnier et al. (2018b). For biogenic silica, an average content of 4.9 $mgSi.gTSS^{-1}$ was applied. This value was estimated by Sferratore et al. (2006) in the Seine basin from measurements of silica in winter in TSS and in soils. Organic carbon diffuse inputs were not directly computed: organic carbon concentrations at the beginning of each day were estimated in every reach from equations linking dissolved organic carbon to discharge and particulate organic carbon to suspended sediments (see Table 3). DOC parameters were set to the mean values of the parameters determined on 50 stations of the Garonne watershed. POC parameters were calculated on the Save tributary, due to limited available data for the Garonne. The simulated DOC and POC concentrations were validated with observations at Verdun-sur-Garonne (see Figure 2), . Once the quantity of COD and COP is determined, RIVE requires their distribution among the biodegradability classes: rapid (5 days), medium to slow (45 days), refractory. For DOC, the values determined for the Seine River were applied i.e., 9, 21, and 70% for rapidly biodegradable, slowly, and refractory respectively (Vilmin et al., 2015). For COP, a similar distribution was based on the percentage curve of POC in relation to TSS for the Garonne River. Specifically, when the TSS concentration is less than 5 mg.l^{-1}, COP consists solely of rapidly biodegradable COP, primarily from phytoplankton for this watercourse; for TSS concentrations between 5 and 20 mg.l^{-1}, the calculated COP is considered to be slowly biodegradable COP, and for TSS concentrations greater than 20 mg.l^{-1}, it is categorized as refractory COP.

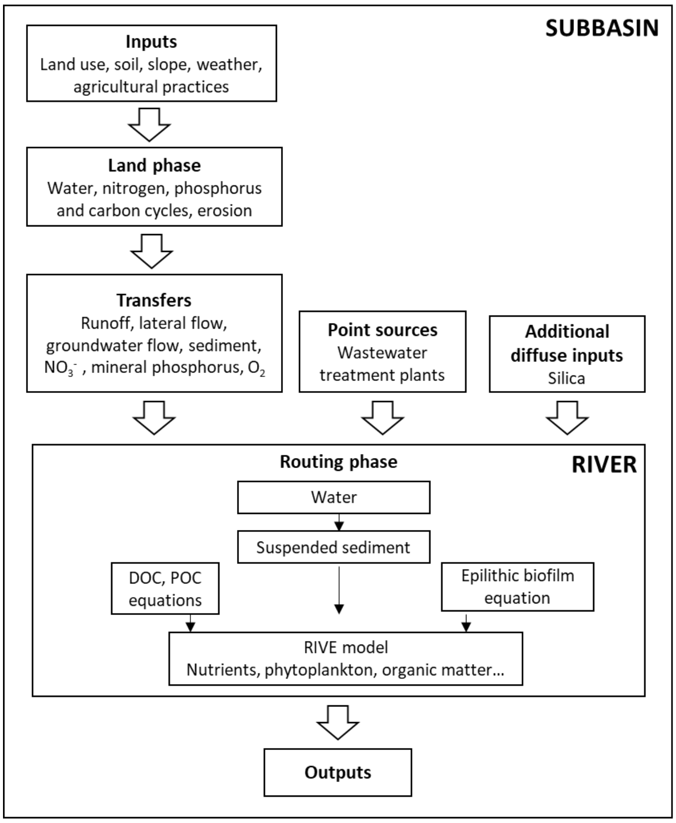

Figure 1: Structure of the SWAT-RIVE model

Table 3 : Methodology applied for RIVE model inputs

Input type	Variable	Method
Climate and hydrology	Discharge, Flow velocity, Depth, Water temperature	Calculated daily by SWAT
Diffuse emissions	Suspended sediment, Nitrate, Mineral phosphorus, Oxygen	Calculated daily by SWAT
	Dissolved silica	Mean concentrations in surface runoff and groundwater flow according to lithology (3 $mgSi.l^{-1}$ for metamorphic rocks, 5 $mgSi.l^{-1}$l for sedimentary rocks (Garnier et al.(2018**b), according to Meybeck (1986**))
	Biogenic silica	A mean content of 4.9 $mgSi.g^{-1}$ of suspended matter (observations in the Seine catchments by Sferratore et al., (2006))
	Dissolved organic carbon (DOC)	$[DOC] = \frac{\alpha.Q}{\beta+Q}$ (Fabre et al., 2020, 2019) With [DOC] DOC concentration ($mg.l^{-1}$), Q discharge (mm), α and β parameters (set to 3.3 and 0.15 respectively)
	Particulate organic carbon (POC)	$\%POC = \frac{d}{TSS-a} + b$ (Boithias et al.,2014; Fabre et al.,2019) With %POC the percentage of POC in the total suspended sediments (TSS), d, a and b parameters (set to 9.40, 5 and 2.1 respectively (Boithias et al.,2014))
Point sources	Discharge, Suspended sediment, Nitrate, Ammonium, Nitrite, Mineral phosphorus, Oxygen	Already in SWAT wastewater treatment plants input files. Loads from Agence de l'eau (http://adour-garonne.eaufrance.fr/), except O_2 : fluxes estimated from capacity and treatment type, according to the methodology described for Seneque-Rivertrahler model in Ruelland et al. (2007b), Seneque 3.6 values
	Nitrifying and heterotrophic bacteria, silica, fecal bacteria, nitrous oxide	Addition to the wastewater treatment plants input files and to SWAT code. Fluxes estimated from capacity and treatment type, according to the methodology described for Seneque-Rivertrahler model in Ruelland et al. (2007b), Seneque 3.6 values

Initialization

Initial values for water column variables were not assigned. Loads come from lands and point sources and a warm-up period determined the initial concentrations. The benthos variables were initialized homogeneously in each reach, using default parameters provided with the historical RIVE code (https://gitlab.in2p3.fr/rive/original_vb_code). The model is supposed to have reached an equilibrium at the end of the warm-up period.

2.1.6. Study site: the Garonne River in its middle course

2.2.1 Study area

The coupled model was validated on a section of the large Garonne River, of 600 km long with a watershed area of 60,000 km², located in southwestern France. The study site is the section from Toulouse (one million inhabitants) to Malause reservoir, halfway between the source and the estuary (Figure 2). The section is 89 km long, seventh order, with a mean annual discharge of 200 m^3 s^{-1}, a mean water velocity 0.5 m s^{-1}, a shallow depth (mean 1 m) and a wide bed (100 m) (Améziane et al., 2003). Garonne River middle course is characterized by two high-flow periods, with hydrological maxima in February and May, and a low-flow period in summer.

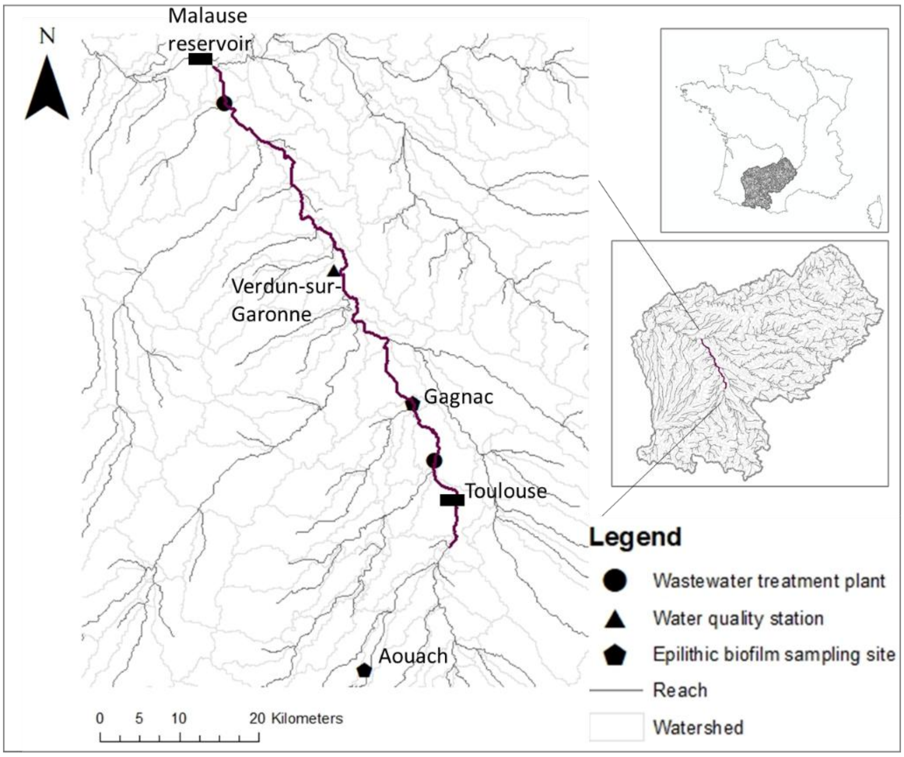

Figure 2: The Garonne River section studied (in bold)

2.2.2 Input data and calibration/validation

The SWAT project used in this study has been set up, calibrated (for the period of 2000-2010), and validated (for the period of 1990-1999) for the study of hydrological and nitrate processes in the whole Garonne watershed by Cakir et al. (2020). Comprehensive details regarding data requirements for this SWAT project can be found in Cakir et al. (2020). The calibration of diffuse nitrate inputs was carried out by Cakir et al. (2020) based on crop yields. SWAT-RIVE validation was carried out for the period from 2000 to 2010, with a warm-up period of three years.. Parameters from the original model were used without change, except for the particulate organic carbon sedimentation sinking rate, which was adjusted to 0.006 $m.h^{-1}$ (instead of xxxx) in accordance with the composition of particulate organic matter in the Garonne watershed. The RIVE subroutine was activated on the whole watershed, providing upstream boundary conditions to the 89 km river section studied. The data used for validation are listed in Table 4.

Table 4: Observation data sources

Data type	Data sources	Resolution		Description
		Spatial	Temporal	
Discharge	https://hydro.eaufrance.fr/	Verdun-sur-Garonne	Daily (2000–2010)	River daily discharge at 1 sampling site
Nutrients, oxygen, chlorophyll a, DOC, POC, suspended sediments	Agence de l'eau (http://adour-garonne.eaufrance.fr/)	Verdun-sur-Garonne gauging station	Punctual (2000–2010)	Concentrations at 1 sampling site, once a month
POC, suspended sediments	(Oeurng et al., 2011)	Save tributary	Daily (2008-2009)	Concentrations at 1 sampling site, once a day
Epilithic biofilm	(Boulêtreau et al., 2006)	Aouach and Gagnac sites	Punctual	2 sampling sites, 1 campaign (2001-2002)

Additional input data required by RIVE concerned silica and carbon diffuse fluxes, as well as supplementary point sources loads (see Table 3). Nineteen additional wastewater treatment plant point sources were added to the original SWAT project due to the significant role of wastewater treatment plant effluents in seeding heterotrophic bacteria (Garnier et al. 1992) and nitrifying bacteria(Brion and Billen, 2000).

2.2.3 Model performance

Indices were calculated to validate the model: the Nash-Sutcliffe efficiency (NSE) index, the coefficient of determination (R^2), and the percent of bias (PBIAS), as described in Moriasi et al. (2015). For water quality modeling, the values considered satisfactory for nitrogen are: NSE > 0.35, R^2 > 0.3 and PBIAS < 30, and good: NSE > 0.5, R^2 > 0.6 and PBIAS < 20 (Moriasi et al., 2015). For phosphorus, the same ranges apply to NSE and PBIAS, and the simulation is considered satisfactory if R^2 > 0.4 and good if R^2 > 0.65. The root mean square error (RMSE) and the Kling-Gupta efficiency criterion (KGE) (modified version, Kling et al., 2012) were also computed for validation purposes.

3. Results and discussion

3.1. Model results and validation

3.1.1 Hydrology

The hydrology simulation on the whole watershed showed satisfactory results, with the simulation reproducing well observed trends (Figure 3, see Cakir et al., 2020 for details on calibration and validation results).

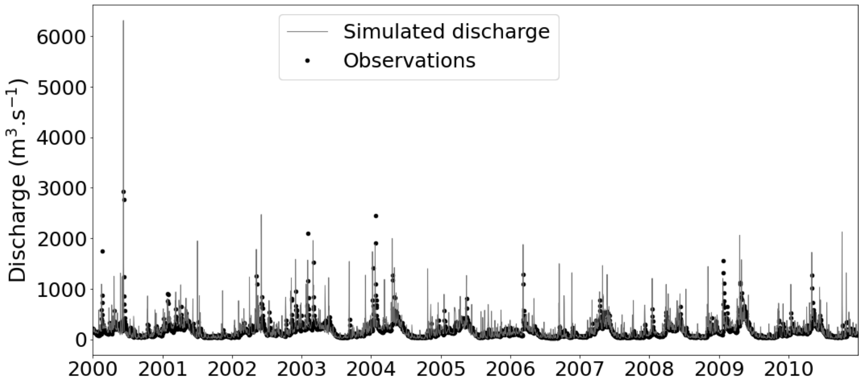

Figure 3: Observed and simulated discharges at Verdun-sur-Garonne on a daily time scale for 2000–2010

3.1.2 Nutrients and oxygen

The concentrations obtained with SWAT-RIVE and SWAT-QUAL2E modules were compared to available observations in the Toulouse-Malause section, specifically at the Verdun-sur-Garonne station, which is located approximately in the middle of the section (Figure 4). Nitrate simulation results using RIVE were close to the concentrations obtained with SWAT with QUAL2E subroutine, but with higher peak concentrations. Nitrite and ammonia were overestimated in both models, especially after 2005. Dissolved silica concentrations were simulated with SWAT-RIVE in accordance with the observations range, although there were limited observations available, only covering the period from 2007 to 2010. Orthophosphates concentrations simulation showed a similar trend in both models.

SWAT-RIVE and SWAT-QUAL2E performance indices were mostly below Moriasi et al. (2015) standards, probably because observations were measured only once a month or less. Nevertheless, nitrate simulation KGE was 0.67 for both models, and PBIAS was satisfactory for SWAT-QUAL2E (14.3) and very good for SWAT-RIVE (-0.9). Compared to SWAT-QUALE, SWAT-RIVE PBIAS performances were better for the nitrogen forms. For orthophosphates, PBIAS performances were lower for SWAT-RIVE, although the concentrations simulated with the two models were close. Simulated nutrients concentrations were in the range of the observations and the seasonal and interannual variations were reproduced.

The oxygen simulation with SWAT-RIVE reproduced the seasonal variations observed and was improved compared to SWAT-QUAL2E, the latter simulating dissolved oxygen drops down to 0.1 $mgO_2.l^{-1}$. The simulations extremely low here for oxygen concentrations are correlated with high CBOD concentrations. These instabilities result from the numerical solving method used in SWAT-QUAL2E. Calibration may address this limitation. Similar extreme low oxygen concentration values simulated with SWAT-QUAL2E were reported by Femeena et al. (2020), and the simulation of dissolved oxygen was improved by modifying dissolved oxygen and CBOD equations, as well as solute dynamics. Comparisons between SWAT-RIVE and SWAT-QUAL2E confirmed the interest in using a biogeochemical model like RIVE, with more processes involved, without calibration or only limited parameter adjustments.

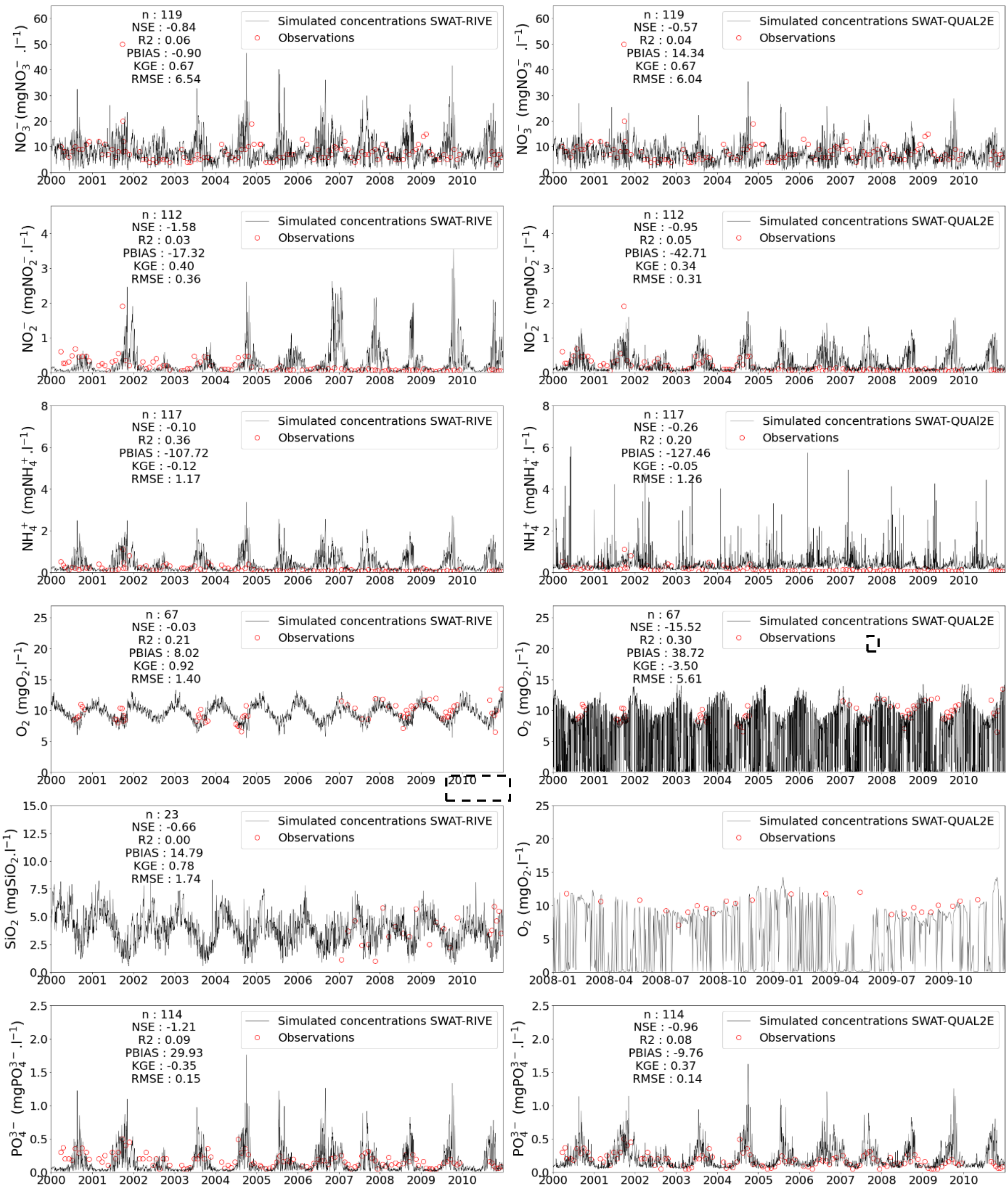

Figure 4: Nutrients and oxygen concentrations simulated daily with SWAT-RIVE model (left) and SWAT-QUAL2E model (right) and observed, at Verdun-sur-Garonne for 2000-2010.

3.1.3 Epilithic biofilm and chlorophyll a

Epilithic biofilm observations have been limited to two sites: the Aouach site upstream of Toulouse, and the Gagnac site downstream of Toulouse. The attached biofilm biomass simulated by the model reproduced the trends observed on the two sites during the campaign (2001-2002) (Boulêtreau et al., 2006) (Figure 5).

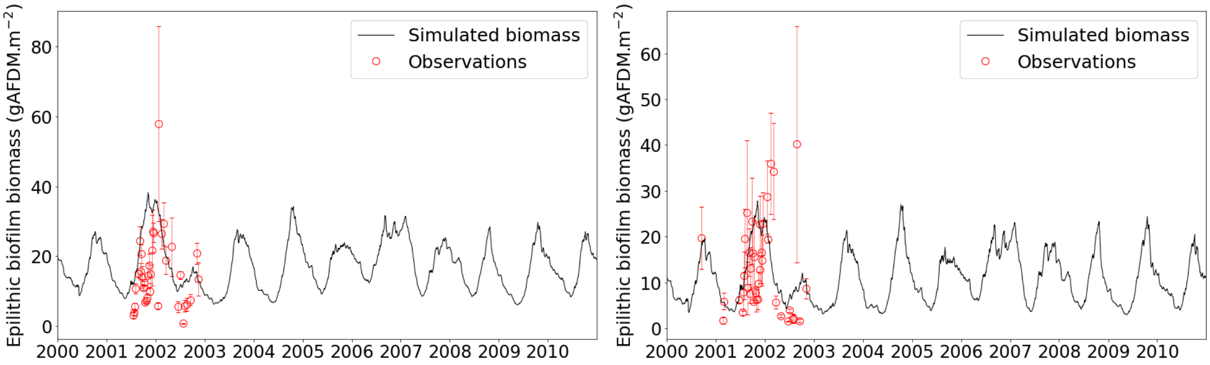

Figure 5: Attached epilithic biofilm biomass simulated by the model and measured at Aouach (upstream of Toulouse) (left) and Gagnac (downstream of Toulouse) (right)

Total chlorophyll a simulated and measured were compared (Figure 6). Simulated chlorophyll a concentrations varies between 1 to 8 µg chla.l^{-1} and observations mostly ranged from 1 (quantification limit) to 6 µg chla.l^{-1}, with four values above 10 µg chla.l^{-1}. Chlorophyll a would mainly originate from detached benthic diatoms (from 94.9 to 98.9 %, see Table 5) while phytoplankton production is low, in line with previous studies on the Garonne River. Tekwani et al. (2013) indeed reported that benthic diatoms accounted for 99% of the water column community in a sampling site 36 km upstream of Toulouse. The percentages of benthic diatoms in suspended algae sampled by Améziane et al. (2003) were lower, between 6 to 52% for Toulouse and Verdun sites, but the conclusions were that the drift of benthic diatoms constituted the major part of chlorophyll a in the Garonne, as high turbulence and short residence time were not favorable to phytoplankton development. Phytoplankton development was observed in tributaries (Tarn, Ariège) or in upstream reservoirs. The development of phytoplankton in reservoirs was not considered here in our modeling approach. Therefore, the observed increase in phytoplankton biomasses cannot be represented by this coupled model at this time. Modeling reservoirs using SWAT-RIVE could be a prospect of improvement, especially since reservoirs influence biogeochemical cycles and can act as sink of N, P and Si, impacting downstream concentrations (Garnier et al., 2000; Maavara et al., 2014; Sow et al., 2016; Yan et al., 2021).

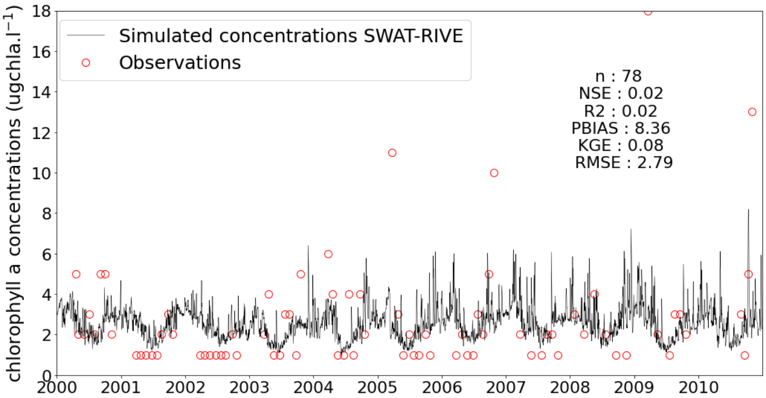

Figure 6: Simulated and observed concentrations of chlorophyll a at Verdun-sur-Garonne for 2000-2010.

Table 5: Phytoplankton species distribution simulated, monthly interannual mean percentage, at Verdun-sur-Garonne for 2000-2010.

Phytoplankton species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chlorophyceae (%)	0.58	0.58	0.63	0.79	1.00	1.62	4.15	4.02	2.33	1.08	0.65	0.63
Cyanobacteria (%)	0.10	0.09	0.10	0.11	0.13	0.16	0.17	0.15	0.12	0.10	0.10	0.10
Diatoms (%)	0.41	0.44	0.51	0.67	0.85	0.95	0.82	0.67	0.48	0.42	0.45	0.43
Drifted benthic diatoms (%)	98.91	98.89	98.76	98.42	98.02	97.27	94.86	95.17	97.07	98.39	98.80	98.83
Total phytoplankton (µg chla.l^{-1})	3.09	3.17	3.11	2.70	2.32	1.97	1.76	2.01	2.50	2.91	2.95	2.94

3.2. Nutrients and organic suspended matter budgets

The coupled model was used to explore the main processes occurring in the drainage network.

3.2.1 Nitrogen budget

On the studied section of 89 km downstream of Toulouse, nitrate would mainly originate from upstream (64%), point sources along the section (25%), and tributaries (11%); nitrite distributed from upstream (48%) and tributaries (44%) and ammonia from point sources (77%) and upstream (22%) (Figure 7).

Nitrate and ammonia point source inputs were high, 25% and 77% of the entries respectively, as the section included Toulouse wastewater treatment plants discharges. In 1992-1993 Muylaert et al. (2009) measured a doubling in dissolved inorganic nitrogen between the upstream and downstream of Toulouse, which was attributed to intensive agriculture and waste discharges. A decrease in ammonia and nitrite measured concentrations was observed from the year 2005. This decline coincided with improvements in nitrogen and phosphorus treatments at Toulouse's main wastewater treatment plant (WWTP Toulouse Ginestous). This decrease was not simulated, as a constant WWTP nutrient discharge was implemented in the model. To account for it, another SWAT point source methodology could be applied, such as yearly records.

Diffuse nitrate inputs were calibrated by Cakir et al. (2020) based on crop yields. Direct diffuse inputs from the lands surrounding the Garonne were dominated by runoff and groundwater loads. This section of the Garonne River contains a large cultivated alluvial floodplain, where groundwater nitrate concentrations can exceed 50 $mgNO_3^-.l^{-1}$ but are much lower in the riparian zone due to plant uptake and denitrification (Pinay et al., 1998, Sánchez-Pérez et al., 2003). In particular, river water recharge dilutes nitrate concentrations and provides dissolved organic carbon promoting denitrification (Sánchez-Pérez et al., 2003). SWAT does not simulate river to aquifer fluxes and denitrification at the surface water-groundwater interface. To model these processes in SWAT, Sun et al. (2016) developed SWAT-LUD and estimated a reduction of 79% of nitrate entering this Garonne floodplain aquifers (Sun et al., 2018). In the SWAT version used in this study, nitrate biological and chemical removal in aquifers is estimated using a half-life parameter. We calibrated this parameter to account for nitrate reduction at the surface water-groundwater interface. With the calibration of this parameter for 2 years, determined by fitting simulated and observed data in low flow period, nitrate removal in aquifers was estimated at 65% of incoming flux into the aquifers in this section of the Garonne watershed.

The in-stream processes led to the consumption of 55 $tonsN.year^{-1}$ of nitrate present in the water column which represented 0.6% of the inputs, mainly lost at the water-benthos interface. In absolute values and percentages of the inputs, nitrate was more removed in autumn (Table 6). Retention in sediments and riparian zones is also a dominant process for nitrogen for studies using Seneque-Riverstrahler (on the Seine, the Somme, and the Scheldt rivers: Thieu et al., 2009: the Red River: Le et al., 2010: the Seine, Haut Loir and Red Rivers: Billen et al., 2018). The mean benthic denitrification rate estimated here was 0.34 $mgN\ m^{-2}\ h^{-1}$, which is low compared to the estimations on the Seine watershed (15 $mgN\ m^{-2}\ h^{-1}$: Billen et al., 2007, obtained with bell jars). Benthic denitrification produced 4.4 $tonsN.year^{-1}$ of nitrous oxide, with 39% produced in autumn. There was no water column denitrification, in accordance with our expectations, as there were no low-oxygen conditions. There was a production of 15 $tonsN.year^{-1}$ of ammonia (1.9% of the inputs), mainly by ammonification. Phytoplankton uptook ammonia (15.5 $tonsN.year^{-1}$) preferentially to nitrate (0.8 $tonsN.year^{-1}$). The N exchanges between the water column and the biofilm were low (around 1 $tonN.year^{-1}$

per N form consumed (NO_3^-, NO_2^- and NH_4^+)), due to an equilibrium between uptake in the light (photosynthesis) and release in the dark (respiration) (Teissier et al., 2007).

13 tonsN.year^{-1} of nitrite was converted into nitrate (9% of the inputs) while only 0.5 tonN.year^{-1} of ammonia was transformed into nitrites. Nitrification rate calculated can be underestimated. Brion and Billen (2000) showed that wastewater treatment plants discharges can represent an important seeding of nitrifying bacteria, controlling nitrification rates. Additional point sources were added to the project to allow this seeding, but they do not represent all urban effluents, only the 26 biggest wastewater treatment plants were implemented.

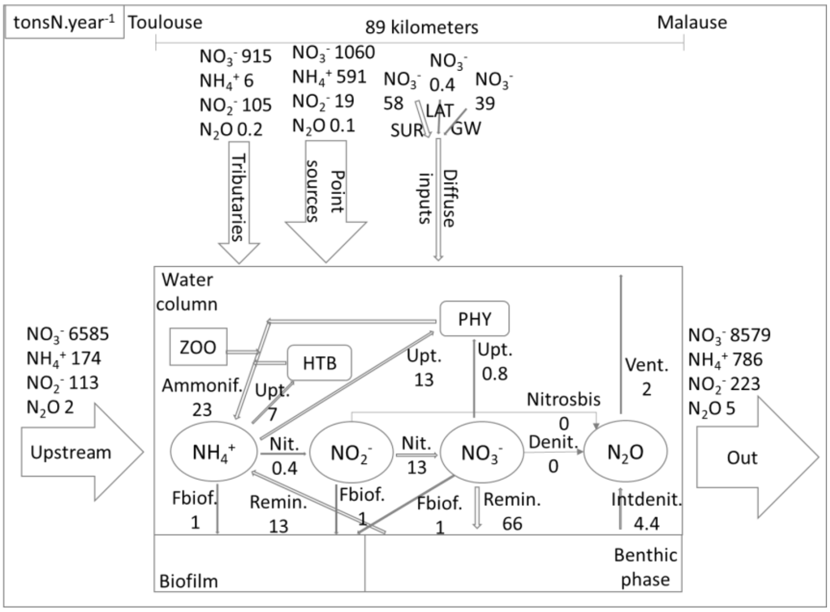

Figure 7: N budget on Toulouse-Malause section estimated with SWAT-RIVE model, interannual averages, in tons of N per year, during the period 2000 to 2010. NH_4^+: ammonia, NO_3^-: nitrate, NO_2^-: nitrite, N_2O: nitrous oxide, PHY: phytoplankton, HTB: heterotrophic bacteria, ZOO: zooplankton, Upt.: phytoplankton or heterotrophic bacteria uptake, Denit: water column denitrification, Nitrosbis: N_2O production by nitrification, Intdenit.: benthic denitrification, Nit.: nitrification, NO3bent : nitrate flux across the water-sediment interface, Amonnif: ammonification by heterotrophic bacteria, zooplankton, and lamellibranch, Vent.: ventilation, Fbiof: exchange with biofilm, SUR : surface runoff inputs, LAT : lateral inputs, GW : groundwater inputs

Table 6: Simulated nitrogen in-stream processes on Toulouse-Malause section, interannual averages (years 2000-2010), in tons per season and in percentage of total inputs (upstream, tributaries, point sources, and diffuse inputs), in italics the highest value for each season.

Variable	Process	Unit	Winter	Spring	Summer	Autumn	Year
NO_3^-	Flux across the water sediment interface	tonsN	*-15.2*	*-16.0*	*-12.7*	*-22.1*	*-66.0*
	Exchange with biofilm	tonsN	0	-0.1	-0.2	-0.6	-0.9
	Nitratation	tonsN	2.2	1.4	2.4	7	13
	Phytoplankton uptake	tonsN	-0.1	-0.3	-0.2	-0.2	-0.8
	Water column denitrification	tonsN	0	0	0	0	0
	Total	**tonsN**	**-12.9**	**-15**	**-11**	**-15.8**	**-54.9**
		%inputs	**0.5**	**0.4**	**0.9**	**1.1**	**0.6**
	Total inputs	**tonsN**	**2350**	**3691**	**1183**	**1410**	**8634**
NO_2^-	Exchange with biofilm	tonsN	-0.2	-0.1	-0.1	-0.4	-0.8
	Ammonium oxidation	tonsN	*-2.2*	*-1.4*	*-2.4*	*-7.0*	*-13.0*
	Nitrite oxidation	tonsN	0.0	0.0	0.1	0.3	0.4
	Total	**tonsN**	**-2.3**	**-1.4**	**-2.4**	**-7.1**	**-13.2**
		%inputs	**2.2**	**3.9**	**18.5**	**8.8**	**5.6**
	Total inputs	**tonsN**	**106**	**36**	**13**	**81**	**236**
NH_4^+	Ammonification	tonsN	2.3	3.3	*6.0*	*11.8*	*23.4*
	Benthic remineralization	tonsN	*6.2*	*6.3*	0.5	-0.5	12.5
	Exchange with biofilm	tonsN	-0.1	-0.1	-0.2	-0.7	-1.1
	Heterotrophic bacteria uptake	tonsN	-0.6	-0.8	-1.7	-3.4	-6.5
	Nitrite oxidation	tonsN	0.0	0.0	-0.1	-0.3	-0.4
	Phytoplankton uptake	tonsN	-2.1	-4.1	-2.5	-4.6	-13.3
	Total	**tonsN**	**5.7**	**4.6**	**2**	**2.3**	**14.6**
		%inputs	**2.9**	**2.3**	**1.6**	**0.9**	**1.9**
	Total inputs	**tonsN**	**195**	**196**	**126**	**253**	**770**
N_2O	Benthic denitrification	tonsN	*0.9*	*0.9*	*0.9*	*1.7*	*4.4*
	Nitrification	tonsN	0	0	0	0	0
	Ventilation	tonsN	-0.2	-0.2	-0.5	-1.1	-2.0
	Total	**tonsN**	**0.7**	**0.7**	**0.4**	**0.6**	**2.4**
		%inputs	**100**	**78**	**133**	**120**	**100**
	Total inputs	**tonsN**	**0.7**	**0.9**	**0.3**	**0.5**	**2.4**

3.2.2 Inorganic phosphorus budget

Urban effluents represented 40% of the section inputs, tributaries 11%, upstream 48%, and diffuse inputs only 1% (Figure 8). According to Bonvallet Garay et al. (2001), Toulouse sewage treatment plant represented between 59 and 67% of total phosphorus input in this sector, before WWTPs treatment were upgraded in the 2000's.

2.4 tonsP.year^{-1} (1.6% of the inputs) was removed from the water column along the section, mainly with total inorganic phosphorus (TIP) sedimentation. Retention, and particularly sedimentation, was higher in spring (Table 7). P retention was experimentally estimated on the field at 22% of total phosphorus and 27% of dissolved reactive phosphorus on the first half of this section in 1997 during low summer flows (Bonvallet Garay et al., 2001). Inorganic phosphorus was also retained using Seneque-Riverstrahler applications on the Seine, Somme, Scheldt rivers (Thieu et al., 2009), and on Red River (Le et al., 2010). In the former study, the dominant processes were phytoplankton uptake, immobilization within the sediment, and deposition (unspecified for the Red River study).

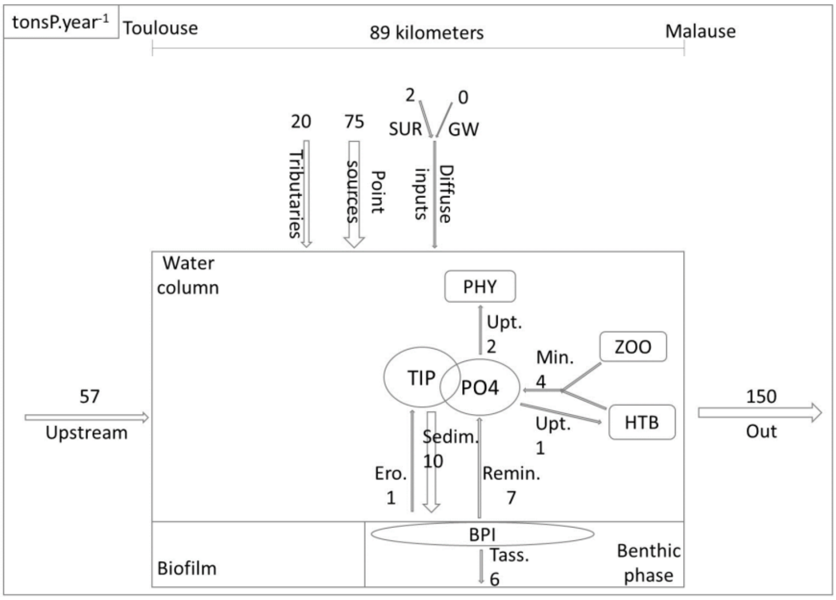

Figure 8: Inorganic phosphorus budget on Toulouse-Malause section estimated with SWAT-RIVE model, interannual averages, in tons of P per year, during the period 2000 to 2010. TIP: total inorganic phosphorus, PO4: orthophosphates, BPI: benthic inorganic phosphorus, PHY: phytoplankton, HTB: heterotrophic bacteria, ZOO: zooplankton, Upt.: phytoplankton or bacteria uptake, Min.: zooplankton and heterotrophic bacteria mineralization, Ero.: BPI erosion, Sedim.: PIT sedimentation, Remin.: PO4 flux associated with benthic remineralization, Tass.: compaction, SUR: surface runoff inputs, GW: groundwater inputs.

Table 7: Simulated inorganic phosphorus in-stream processes on Toulouse-Malause section, interannual averages (years 2000-2010), in tons per season and in percentage of total inputs (upstream, tributaries, point sources, and diffuse inputs), in italics the highest value for each season.

Variable	Process	Unit	Winter	Spring	Summer	Autumn	Year
TIP	Benthic remineralization	tonsP	1.6	1.7	1.1	2.2	6.6
	Erosion	tonsP	0.1	0.3	0.1	0.1	0.6
	Heterotrophic bacteria uptake	tonsP	-0.1	-0.1	-0.3	-0.6	-1.1
	Phytoplankton uptake	tonsP	-0.4	-0.8	-0.4	-0.8	-2.4
	Sedimentation	tonsP	*-2.5*	*-3.6*	*-1.5*	*-2.5*	*-10.1*
	Zooplankton and heterotrophic bacteria mineralization	tonsP	0.4	0.6	1	2	4
	Total	**tonsP**	**-0.9**	**-1.9**	**0**	**0.4**	**-2.4**
		%inputs	**3.4**	**4.7**	**0**	**0.8**	**1.6**
	Total inputs	**tonsP**	**37**	**41**	**26**	**49**	**153**

3.2.3 Silica budget

Dissolved silica (DSI) main inputs are upstream (77%) and tributaries (21%), biogenic silica (BSI) are point sources (46%), upstream (29%), and tributaries (24%). Pyrenean floods provide the majority of dissolved silica exported by the Garonne (Semhi et al., 2000). Dissolved silica diffuse inputs were estimated with constant concentrations that varied according to lithology,Future development should be made to estimate silica diffuse inputs with SWAT model. Lechuga-Crespo et al. (2021) developed SWATLitho, which adds a lithology layer and computes the major ion fluxes (excepted silica) reaching streams from chemical weathering of rocks. The average content of 4.9 $mgSi.gTSS^{-1}$ applied for biogenic silicacould be adapted with specific measurements in the modeled watershed. However, this value measured on the Seine watershed was also used by Liu et al. (2020) for modeling on the Rhine and Yangtze rivers (IMAGE-DGNM model, inspired by Riverstrahler) and Thieu et al. (2009) for the Riverstrahler modeling of the Somme and Scheldt rivers. Regarding point sources, biogenic silica loads are higher than dissolved silica. Conversely, Sferratore et al. (2006) measured dissolved silica loads almost twice as high as biogenic silica loads for Achères WWTP (Seine watershed). There were no available data on silica discharges for the Garonne watershed. Silica loads per inhabitant and treatment types used could be adapted with measurements.

DSI was consumed along the section (-19 $tonsSi.year^{-1}$). The dominant processes for DSi were a consumption by diatoms and drifted benthic diatoms, and a production by remineralization of DSI at the water-sediment interface (Figure 9). Net removal only represented 0.1% of the inputs: dissolved silica uptake by phytoplankton (84 $tonsSi.year^{-1}$) was compensated by dissolved silica flux from the benthos (64 $tonsSi.year^{-1}$). Diatoms uptake was higher in spring and autumn. In summer, dissolved silica was not consumed but slightly produced (Table 8). 8 $tonsSi.year^{-1}$ of biogenic silica (BSI) was formed (3% of the inputs) with the main production process being phytoplankton mortality and retention process through biogenic silica sedimentation. In winter, BSi retention logically exceeded production due to low biological activity. .

Muylaert et al. (2009) highlighted the negative correlation between measurements of dissolved silica and chlorophyll a concentrations downstream of Toulouse, suggesting the consumption of dissolved silica by diatoms. However, uptake and dissolution rates were not measured. Again, Seneque-Riverstrahler results also showed dissolved silica flux from benthic biogenic silica dissolution is not mentioned as dominant, unlike diatoms uptake and biogenic silica deposition (Thieu et al., 2009; Le et al., 2010). Nevertheless, the benthic algorithm used in this study is the new version (Billen et al., 2015). The low silica retention should also be related to the low simulated phytoplankton concentrations, compared to the observed ones, in the absence of water quality simulation for upstream reservoirs.

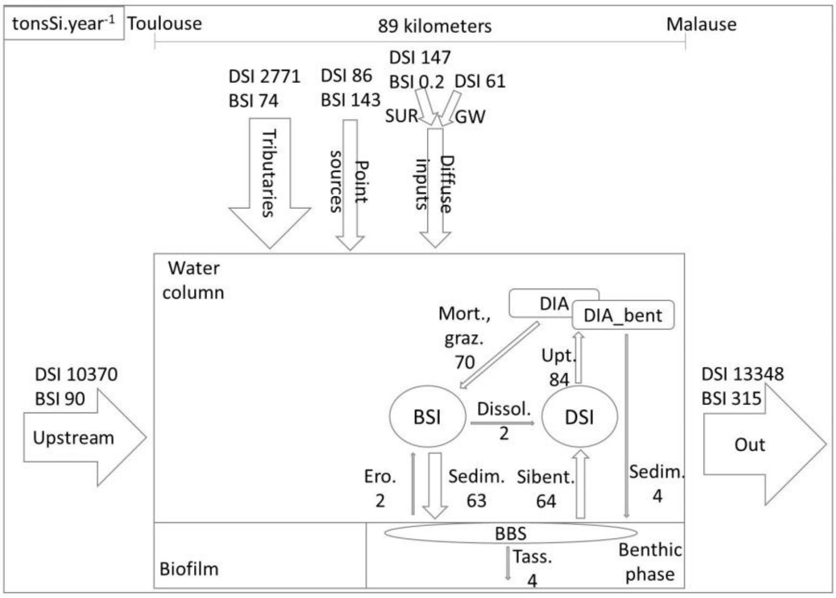

Figure 9: Silica budget on Toulouse-Malause section estimated with SWAT-RIVE model, interannual averages, in tons of Si per year, during the period 2000 to 2010. DSI: dissolved silica, BSI: biogenic silica, BBS: benthic biogenic silica, DIA: diatoms, DIA_bent: drifted benthic diatoms, Upt.: diatoms and benthic diatoms uptake, Mort. Graz: diatoms and benthic diatoms mortality or grazed, Dissol: SIB dissolution, Sibent.: dissolved silica flux across the water-sediment interface, Sedim: SIB or diatoms/benthic diatoms sedimentation, Eros: BBS erosion, Tass: compaction, SUR: surface runoff inputs, GW: groundwater inputs.

Table 8: Simulated silica in-stream processes on Toulouse-Malause section, interannual averages (years 2000-2010), in tons per season and in percentage of total inputs (upstream, tributaries, point sources, and diffuse inputs), in italics the highest value for each season.

Variable	**Process**	**Unit**	**Winter**	**Spring**	**Summer**	**Autumn**	**Year**
DSi	Diatoms and drifted benthic diatoms uptake	tonsSi	*-12.4*	*-26.4*	-15.9	*-29.5*	*-84.2*
	Flux across the water-sediment interface	tonsSi	7.4	13.8	*17.8*	24.8	63.8
	SIB dissolution	tonsSi	0.2	0.3	0.5	0.8	1.8
	Total	**tonsSi**	**-4.8**	**-12.3**	**2.4**	**-3.9**	**-18.6**
		%inputs	**0.1**	**0.2**	**0.1**	**0.2**	**0.1**
	Total inputs	**tonsSi**	**3636**	**5877**	**1995**	**1858**	**13365**
BSi	Diatoms and drifted benthic diatoms mortality or grazed	tonsSi	10.5	*19.5*	*14.3*	*26*	*70.3*
	Dissolution	tonsSi	-0.2	-0.3	-0.5	-0.8	-1.8
	Erosion	tonsSi	0.4	1.5	0.3	0.2	2.4
	Sedimentation	tonsSi	*-12.8*	-17.7	-11.6	-20.6	62.7
	Total	**tonsSi**	**-2.1**	**3**	**2.5**	**4.8**	**8.2**
		%inputs	**3.2**	**3.5**	**4.2**	**5.0**	**2.7**
	Total inputs	**tonsSi**	**67**	**85**	**60**	**96**	**308**

Organic suspended matter budget

Organic suspended matter was represented in RIVE by several variables (phytoplankton, nitrifying and heterotrophic bacteria and particulate non-living organic matter), described in mgC.l^{-1} (Figure 10). The in-stream processes resulted in the retention of heterotrophic bacteria and particulate non-living organic matter through sedimentation. The input-output budget for the phytoplankton species showed a production of biomass, with the drift of benthic diatoms and their growth exceeding mortality, sedimentation, and lamellibranchs filtration.

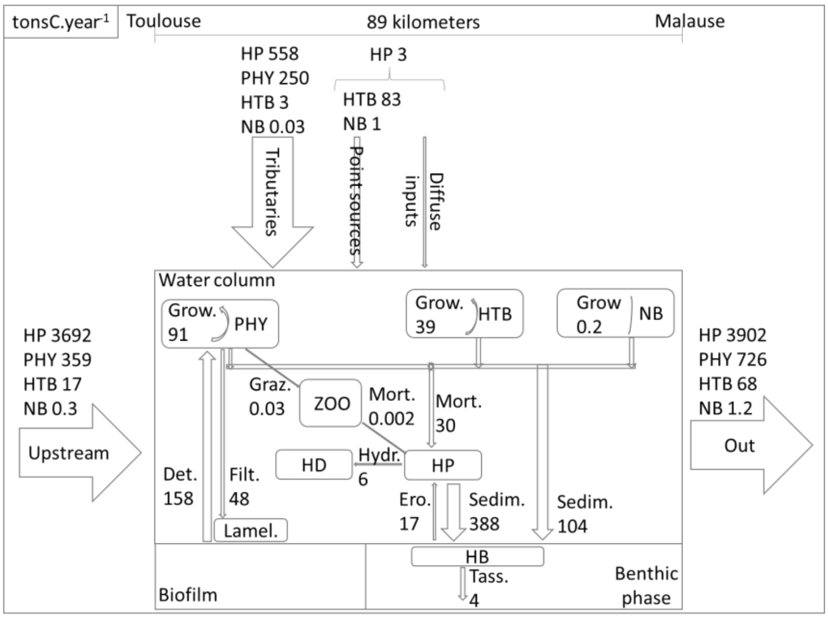

Figure 10: Organic suspended matter budget on Toulouse-Malause section estimated with SWAT-RIVE model, interannual averages, in tons of C per year, during the period 2000 to 2010. PHY: phytoplankton, HTB: heterotrophic bacteria, NB: nitrifying bacteria, ZOO: zooplankton, HP: particulate non-living organic matter, HD: dissolved non-living organic matter, Grow.: growth, Mort.: mortality, Hydr.: hydrolysis, Ero.: benthic organic matter erosion, Sedim.: sedimentation, Tass.: compaction, Det.: biofilm algae detachment, Lamel.: lamellibranch, Filt.: lamellibranch filtration, Graz.: grazing.

3.3. Coupling SWAT and RIVE models: advantages and difficulties

To be in accordance with SWAT structure, RIVE equations replace QUAL2E equations, and thus RIVE is applied on reach sections which have different length and residence time. SWAT can be run in sub-daily time step; however, it would require sub-daily rainfall data, which were not available.

Calculation time was similar for SWAT-RIVE and SWAT- QUAL2E models. With RIVE model, the mass balance between the water column and the benthic zone is closed. No numerical instabilities were noted, the numerical scheme applied was adequate for this watershed. However, Woldegiorgis et al. (2017)'s new quasi-analytical solution could be considered for further development, to compare the consistency and stability of SWAT-RIVE solutions.

Whereas SWAT hydrology and diffuse inputs need to be calibrated, an advantage of implementing the RIVE model was it does not require calibration, parameters being determined independently from the observations. However, some adjustments of the parameters can be made in the range of their experimental determination (e.g., Garnier et al., 2000; 2002). Minaudo et al. (2018) pointed out the need to calibrate such parameters as suspended sediment sedimentation velocity and the two parameters determining phosphorus adsorption. In this study, the particulate organic matter sinking rate was adjusted from 0.05 $m.h^{-1}$ to 0.006 $m.h^{-1}$, as it appeared previously high considering the composition of particulate organic matter in the Garonne watershed, especially for slowly biodegradable matter, which is mainly composed of tree leaves reaching the water column.

Regarding validation, there was a lack of data concerning several variables of RIVE model, in particular zooplankton, heterotrophic bacteria, and nitrifying bacteria biomasses, so the simulated concentrations were not compared with such observations. Their correct representation is essential for the validity of the model, as they intervene in the biogeochemical cycles where variables are strongly interdependent (Minaudo et al., 2018). The parameters used in their representation do not justify calibration because they have been determined directly from experiments based on key physico-chemical parameters such as temperature dependency. However, measured data could be further used to validate the input settings, such as the estimations made for bacterial point sources.

The SWAT model version used in this study did not simulate silica and organic matter diffuse inputs, required by RIVE, so that alternative methods were applied for their input to the Garonne reach (discussed in section 3.2.3 for silica). DOC and POC concentrations were estimated at the beginning of each simulated day in every reach based on previously established relationships between DOC and discharge, and POC and TSS in the Garonne watershed (see Table 3). The DOC equation was validated on 58 watersheds out of 70 around the world (Fabre et al., 2020) and the POC one on the Save, a Garonne tributary, the Yenisei, the Mississippi, the Murray, the Oubangui and Hwang Ho (Boithias et al., 2014; Fabre et al., 2019; Fabre, 2019). Recent SWAT developments concerned the integration in SWAT of DOC and POC fluxes from land to river reaches (Du et al., 2019; Qi et al., 2020; Zhang et al., 2013), but they were not integrated into the SWAT version available. On the other hand, while using RIVE, measurements of organic carbon biodegradability specific to the studied area would allow for a more precise refinement of the distribution within the biodegradability classes of the RIVE model.

4. Conclusion

The biogeochemical RIVE model was integrated into the river basin SWAT code. The coupled SWAT-RIVE model was successfully applied to a section of the Garonne in its middle course. We added a biofilm equation to accurately represent the algae communities in the river, dominated by drifted benthic diatoms. The simulated nutrients and oxygen concentrations and associated fluxes varied within the range of observed data, and the seasonal variations were adequately reproduced.The coupled model represents various additional variables, such as silica or phytoplankton major groups and it provides more information about the biological processes occurring in the drainage network compared to the previous version, including the removal of nitrate by benthic denitrification. Finally, it allows the user to avoid calibration for in-stream water quality parameters. Future improvements can be achieved by modifying and using SWAT model to calculate organic carbon and silica diffuse inputs from watersheds to streams, and by applying RIVE model not only to streams but also to reservoirs, which are major components of hydrosystems.

Software availability

- The Soil and Water Assessment Tool (SWAT) is freely available in https://swat.tamu.edu/software/. The version used is SWAT2012 VER 2016/Rev 664.
- RIVE is currently being revised and unified by the Metis Lab developers' team, to be open soon to the scientific community through a collaborative platform (https://gitlab.in2p3.fr/rive).
- Source code of the modified model presented in this paper (SWAT-RIVE) will be provided on the collaborative platform (https://gitlab.in2p3.fr/rive).

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