

### S1. The benthic biogeochemistry module

#### S1.1. The nitrogen cycle in the sediment layer

The processes involving *N* in the sediment layer in the model are described by the following state variables, as described in [86] and [87-96]:

- SON* for organic *N* in sediment
- SNH* representing total  $NH_4-N$  in sediment pore water
- SN03* indicating total  $NO_3$  in sediment,
- *SNIM* for immobilized *N* in sediments.

Within the sediment, *N* can undergo mineralization into  $NH_4$ , while  $NO_3$  may be denitrified or exchanged with inorganic *N* in the water column.  $NH_4$  and  $NO_3$  are considered as inorganic *N* (*IN*), with the assumption that the ratio of  $NH_4$  to  $NO_3$  in the water column just above the sediment surface mirrors that of the sediment. Additionally,  $NH_4$  in sediment may undergo exchange with inorganic *N* or be nitrified into  $NO_3$  in the uppermost sediment layer with the presence of  $O_2$ . It is assumed that a fraction is available for nitrification and for flux across the sediment surface. Given that nitrification is an aerobic process, it is confined to the sediment layer with  $O_2$ .

The processes involving the *N*-cycle in the sediments are depicted in Figure 3 and represent by the following differential equations:

$$\frac{d SON}{dt} = RSON - RSONNH - RSNIM \quad (S1)$$

$$\frac{dSNIM}{dt} = RSNIM + RDENIT \quad (S2)$$

$$\frac{d SNH}{dt} = \frac{RSONNH - RSNIT - FNH}{(1 - DM) * VF * HDO2} \quad (S3)$$

$$\frac{d SNO3}{dt} = \frac{RSNIT - RDENIT - FNO3}{(1 - DM) * VF * HDS} \quad (S4)$$

The variables *DM*, *VF*, *HDS*, and *HDO2* denote, respectively, the fraction of dry sediment matter in water (g/g), the specific gravity (g/m<sup>3</sup>), the depths of the active sediment layer (m), and the depth of  $O_2$  penetration into the sediment. The latter depends on the thickness of the water layer above the sediment (m) and is calculated accordingly:

$$HDO2 = HKA + KKB * DO - KKC * ODSC * WADE \quad (S5)$$

where *HKA* represents the minimum depth required for  $O_2$  penetration (m), while *KKB* and *KKC* are specific parameters governing the penetration of  $O_2$  into sediment (m<sup>4</sup>/g  $O_2$ ). *DO* denotes the dissolved oxygen concentration. Additionally, *ODSC* and *WADE* stand for the total sediment oxygen consumption (g  $O_2$ /m<sup>3</sup>/day) and the thickness of the water layer above the sediment layer (m), respectively.

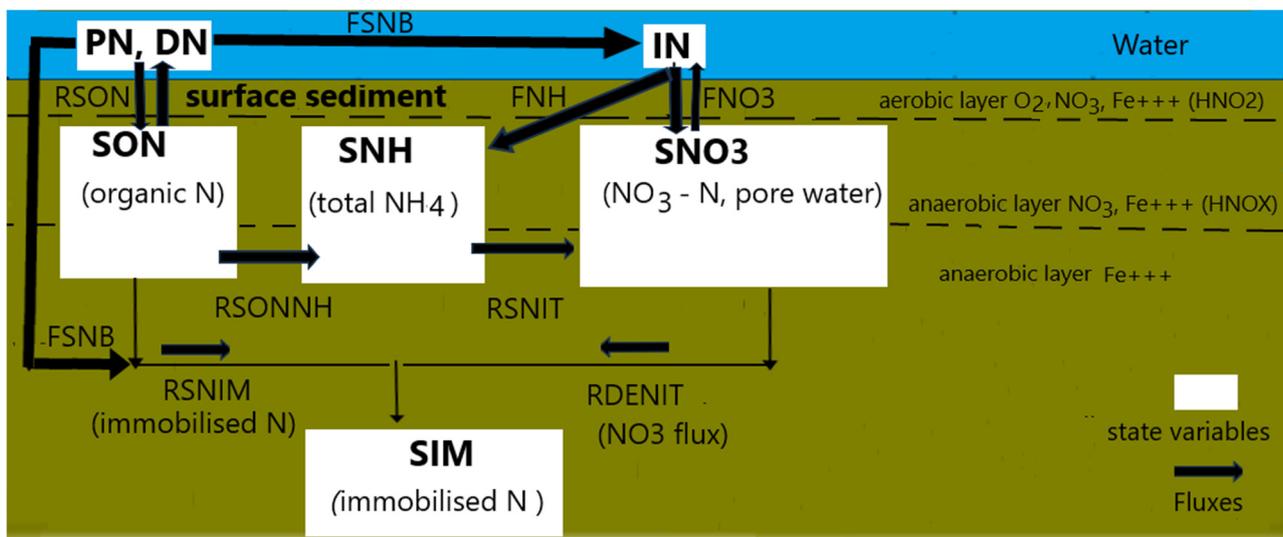


Figure S1\_1. The N-cycle in the sediments.

Each equation within the (S1-S4) system, as depicted in Figure S1\_1, incorporates specific processes calculated as linear functions of the following biogeochemical state variables described below.

**RSON** accounts for the remaining organic *N* in the sediment that contributes to the **SON** pool. It is considered as a linear function of:

- the sedimentation of the phytoplankton *N* (*PN*), *SEPN*, ( $g\ N\ m^{-3}\ day^{-1}$ ), the sedimentation of the detritus *N* (*DN*), *SEDN*, ( $g\ N\ m^{-3}\ day^{-1}$ )
- the input to sediment of *N* from dead eelgrass, *SEEN*, ( $g\ N\ m^{-3}\ day^{-1}$ ), and of the fraction of the newly settled organic *N* which is fast mineralized, *FSNB* ( $g\ N\ m^{-2}\ day^{-1}$ ), which linearly depend on *SEPN*, *SEDN* and *SEEN*, as well as on a function *TETN* ( $T^{-20}$ ), where *T* is the water temperature and *TETN* is a number of the order of 1.0.

**RSONNH** accounts for the fraction of **SON**, which is mineralized into  $NH_4$ . It is supposed proportional to:

- SON** (with a constant mineralized rate) and temperature dependent (*TETN* ( $T^{-20}$ )).

**RSNIM** accounts for the fraction of the settled nitrogen which is assumed to be buried into the sediment layer. It is calculated as a linear function of the of the following variables described below:

- the sedimentation of the plankton *C*, *SEPC* ( $g\ C\ m^{-3}\ day^{-1}$ )
- the sedimentation of the detritus *C*, *SEDC* ( $g\ C\ m^{-3}\ day^{-1}$ )
- the input to sediment of *C* from the dead eelgrass, *SEEC* ( $g\ C\ m^{-3}\ day^{-1}$ )
- the ratio *N:C*, of immobile *N* below which no mineralization occurs
- KNIM* and *WADE*.

**RDNIT** ( $g\ N\ m^{-2}\ day^{-1}$ ) accounts for the flux of  $NO_3$  into sediment, corresponding to a denitrification process. It is calculated with the help of a Fick law on the concentration of  $NO_3$  in sediment ( $g\ NO_3-N/m^3$ ) for the water sediment interface. A more complex formulation is adopted for the deeper layers of the sediment layer based on, the square root function of *DIFN*, the maximum denitrification rate *DNM3* and of *TETN* ( $T^{-20}$ );

**RSNIT** ( $g\ N\ m^{-2}\ day^{-1}$ ) accounts for the nitrification of  $NH_4$  in the sediment. It is supposed linear dependent on the water temperature *TETN* ( $T^{-20}$ ) and on two Monod-kinetics function for  $NH_4$  in the sediment, and for the squared of  $O_2$  concentration in the pore water, respectively. The potential nitrification rate in sediment at 20 °C is defined as *KNIT*.

**FNH** ( $g\ N\ m^{-2}\ day^{-1}$ ) accounts for the flux of **SNH** between the sediment and the pore water. It is set proportional to *FNHNO3* ( $g\ N\ m^{-2}\ day^{-1}$ ) and to the ration rate  $NH_4/(NH_4+NO_3)$ :

-**FNO3** ( $g\ N\ m^{-2}\ day^{-1}$ ) corresponds to the flux of  $NO_3$  between the bottom sediment layer and the water. It is calculated as:  $FNO3 = FNHNO3 - FNH$ :

$FNHNO_3$  corresponds to the flux of  $NH_4+NO_3$  between the sediment and the pore water, which is calculated with the help of a Fick law on the gradient of concentration of  $NH_4 + NO_3$  relatively to  $IN$ :

$$FNHNO_3 = DIFN * \frac{SNH+SN03-IN}{KDOX} \tag{S6}$$

where  $HDOX$  is the depth of the anoxic  $NO_3$  sediment layer and  $DIFN$  ( $m^2/day$ ) is the diffusion coefficient of  $NO_3$  into the sediment layer.

### S1.2. The phosphorus cycle in the sediment layer

Phosphorus interacts with solids interface in various ways, including exchanges occurring at the solid-liquid interface and precipitation/dissolution reactions involving solid-phase elements such as iron, calcium, and aluminum as described in [86] and [87,88, 90, 93, 97-99]

The processes involving  $P$  in the sediment layer are described in the model by the following state variables:

- $SOP$  which accounts for the organic  $P$  in sediment, which is mineralized into  $PO_4$ . The exchanges of  $SOP$  through the sediment surface occur through sedimentation of algae and detritus  $P$ . A fraction of the settled  $SOP$  can be as well mineralized into  $PO_4$  on the sediment surface;

- $SIP$  which accounts for the total  $PO_4-P$  in sediment pore water;

- $SPFE$ , which accounts for the sediment  $PO_4-P$  adsorbed to  $Fe^{+++}$ ; and  $SPIM$  which accounts for the immobile  $P$  in the sediment.

The processes involving the  $P$  cycle as depicted in Figure 3 are represented by the following differential equations:

$$\frac{d SOP}{dt} = RSOP + ROPSIP - SPIM \tag{S7}$$

$$\frac{d SIP}{dt} = \frac{ROPSIP - RFSEIP - FSIP}{(1 - DM) * VF * HDS} \tag{S8}$$

$$\frac{d SPFE}{dt} = RFESIP \tag{S9}$$

$$\frac{d SPIM}{dt} = RSPIM \tag{S10}$$

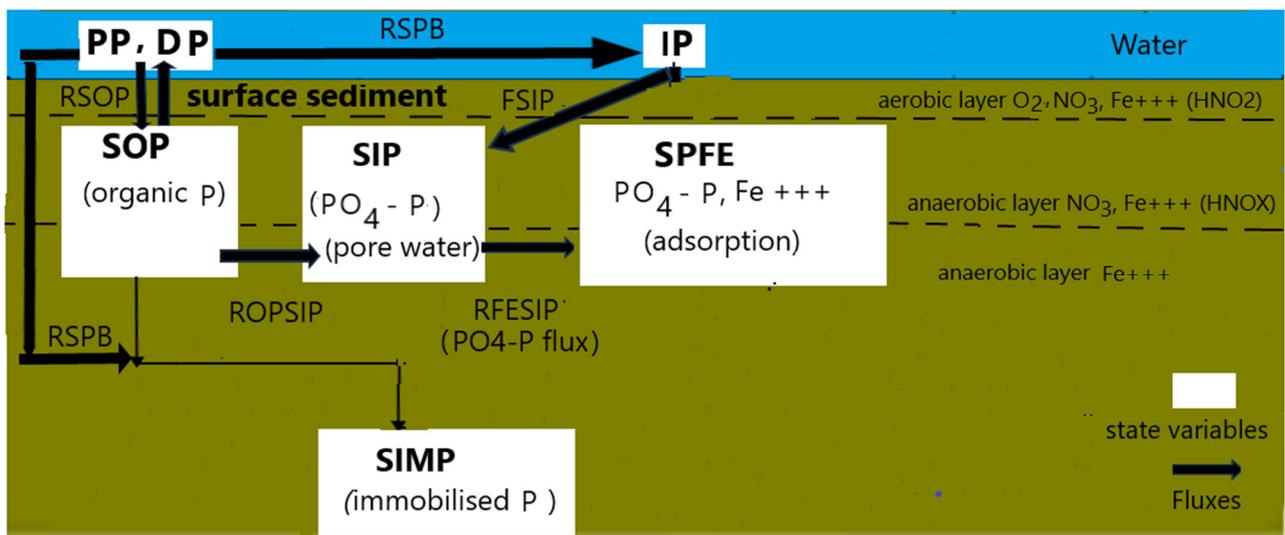


Figure S1\_2. The  $P$ -cycle in the sediments.

Each equation within the (S7-S10) system, as depicted in Figure S1\_2, incorporates specific processes calculated as linear functions of the following biogeochemical state variables described below.

**RSOP** accounts for the remaining organic in the sediment  $P$  which flows into the organic  $P$  pool. It is considered as a linear function of the following variable:

- the sum of the sedimentation of the plankton  $P$ ,  $SEPP$  ( $\text{g P m}^{-3} \text{ day}^{-1}$ ), of the sedimentation of the detritus  $P$ ,  $SEDP$  ( $\text{g P m}^{-3} \text{ day}^{-1}$ );

- the input to sediment of  $P$  from the dead eelgrass,  $SEEP$  ( $\text{g P m}^{-3} \text{ day}^{-1}$ ), discounted from  $FSPB$ ; The last one corresponds to fraction of the settled organic  $P$  which is mineralized on the sediment surface;

- the dept of the water layer above the sediment layer,  $DEWA$ ;

**ROPSIP** accounts for the fraction of the organic  $P$  in the sediment,  $SOP$ , which is mineralized into  $PO_4$ , and is released into the pore water pool of  $PO_4$  ( $SIP$ ). It is supposed to be temperature dependent ( $TETN^{(T-20)}$ ) and a linear function of  $SOP$ , with a constant rate  $RSP1$ .

**FSIP** accounts for the flux of  $PO_4$  between sediment and water. It is calculated with the help of a Fick law on the concentration of  $SIP-IP$  in the sediment layer, with a constant diffusion coefficient,  $KFIP$  ( $\text{m}^2/\text{day}$ ), and inversely proportional to corresponding to the depth of  $PO_4$  penetration in sediment,  $HDOX$  (m).

**RFSEIP** accounts for the sorption and desorption of  $PO_4$  to  $Fe^{+++}$ . It is supposed to obey to a Monod-kinetics for  $SIP$  and a linear function of:

- the  $Fe^{+++}$  concentration in the surface sediment,  $KFE$  ( $\text{gP/gFe}$ );

- the chemisorption of  $P$  to  $Fe^{+++}$ ,  $KFEPO$  ( $\text{g P/g Fe}$ );

- the depth penetration depth, the same as  $HDOX$  (m), and of  $DM$  ( $\text{gDM/gW}$ ) and  $VM$  ( $\text{g W/g cm}^3$ ), which are respectively the dry matter of sediment relative to the water mass ( $W$ ), and the specific gravity.

It should be pointed out that in the model:

- the  $Fe$  content in the  $O_2$  or  $NO_3$  layer will only be considered in the oxidized form.

- the time rate of  $SPIM$ , which accounts for the immobile fraction of  $P$  in the sediment is supposed to be equivalent to the rate of burial of organic  $P$  in sediment,  $RSPIM$ . The last one is considered proportional to the organic  $P$  fraction,  $RSOP$ , with a constant rate,  $KPIM$ .

**Table S2\_1: Main parameters for the N and P cycle in the sediment 107=58**

Parameters for the N and P cycle in the sediment	range	Value	References
Fraction of settled N mineralised on sediment	0-1	0.1	-
Mineralisation of SON, 1/day	0-0.1	0.0024	[62]
N:C ratio of immob. Org. N in sediment, g N/g C	0.064	0.064	[62]
Teta. mineralisation of SON in sediment	1.04	1.04	-
Nitrification rate sediment, g N/m <sup>3</sup> /day	0-150	84	[62-65]
Denitrification rate sediment, g N/m <sup>3</sup> /day	0-500	84	[62-65]
Nitrification sediment half saturation conc., g N/m <sup>3</sup>	0.5	0.5	-
Halfsaturation conc. For eelgrass uptake of SNH, g N/m <sup>3</sup>	0.9	0.9	[66-68]
Teta for temperature. mineralisation of SOP	1.04	1.04	-
Immobile P fraction of settled P	0.15	0.15	[62]
Fraction of settled P mineralised at surface	0-1	0.1	-
Mineralisation of SOP, 1/h	0-0.1	0.0024	[62]
Depth of active sediment layer, m	0-1	1	-
Chemosorption of P to Fe <sup>+++</sup> , g P/g Fe	0-1	0.005	[69, 71, 72]
Const1. DO penetration in sediment. m	0-0.1	0.00124	[73]
Const2. DO penetration in sediment, m <sup>3</sup> day/DO	0-0.01	0.00132	[73]
Const3. DO penetration in sediment, m/DO	0-0.1	0.000403	[73]
Diffusion for SIP, m <sup>2</sup> /day	0-0.001	0.000024	[73]
Halfsaturation Fe <sup>+++</sup> sorption of SIP, g P/m <sup>3</sup>	0.25	0.25	[71, 72]
Rate for Sorption and desorption of PO <sub>4</sub> to Fe <sup>+++</sup> , 1/day	0.0004-0.001	0.001	[68]
Diffusion of NO <sub>3</sub> and NH <sub>4</sub> in sediment, m <sup>2</sup> /h	0-0.001	0.000024	[64, 74]
Teta temp dependency of denitrification	1.087	1.087	[75]

SON-Sediment organic N; SOP-Sediment organic P; SIP-Sediment inorganic P, DO-Dissolved oxygen; SNH-Sediment NH<sub>4</sub>.

The sensitivity analysis presented here focuses on parameters related to the nitrogen (N) and phosphorus (P) cycles in sediments, as they encompass both inorganic and organic phases. These parameters play a crucial role in influencing the dynamics of TN and TP, making them key factors to consider in model validation. The following experiments were considered for a typical spring situation.

-**Sens1:** Sediment mineralization rate for organic N and P, *Sed\_minerali\_rt\_NP* (1/day).

-**Sens2:** Nitrification and Denitrification rates, maximum values per m<sup>3</sup> of sediment, *Nit\_Dnit\_rt* (g N/(m<sup>3</sup> day)).

-**Sens3:** NO<sub>3</sub> penetration rate into sediment, *NO3\_penet\_rt* (1/day).

-**Sens4:** Diffusion coefficient of the NO<sub>3</sub> and NH<sub>4</sub> into sediment, *Diffu\_coef* (m<sup>2</sup>/day).

-**Sens5:** Fe-P sorption and desorption of PO<sub>4</sub> to Fe<sup>++</sup> into sediment, maximum value, *Fe\_Psor\_dsor* (g P/ g) Fe).

-**Sens6:** Fraction of the settle N and P to mineralization and immobilization, *Fra\_N\_mineral./immob.* and *Fra\_P\_mineral./immob* (number).

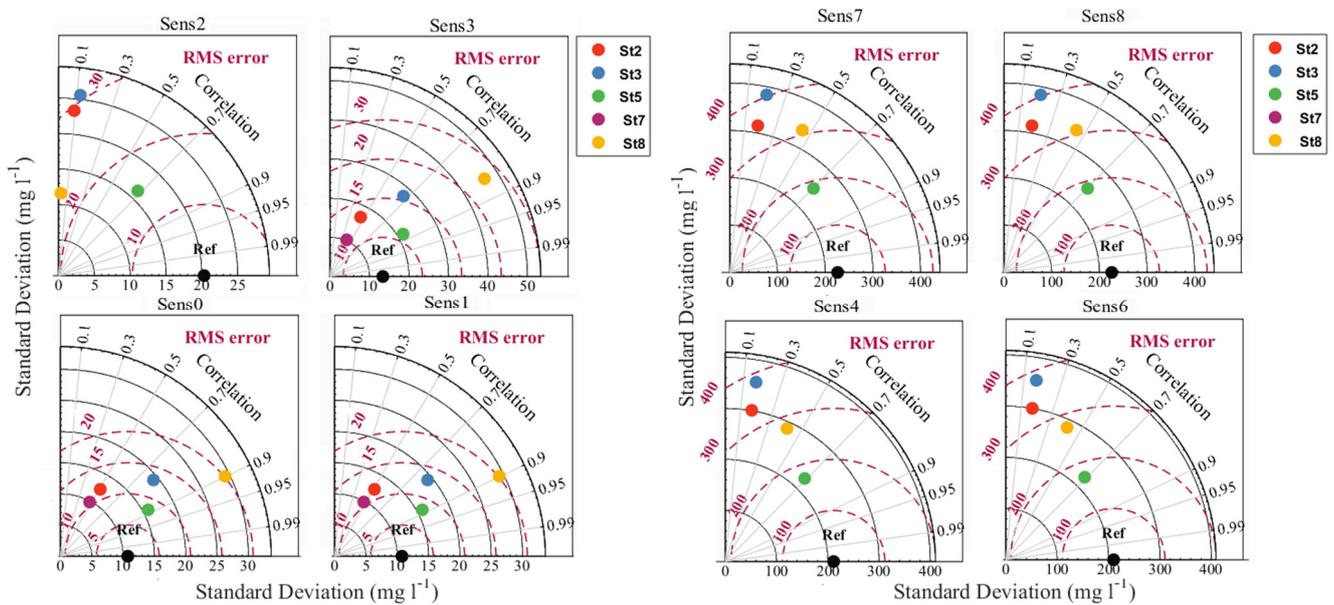
-**Sens7:** Oxygen penetration into sediment constant, *Oxygen\_pene1* (m).

-**Sens8:** Oxygen penetration into sediment constant, *Oxygen\_pene2* m<sup>2</sup>/(g DO).

The parameters and their reference values are listed in Table 6 (see Annex for the remaining parameters).

**Table S2\_2.** The sensitivity parameter for the experiments. (a)Baseline (calibrated values); (b) Experiment.

Parameter	Sens1	Sens2	Sens3	Sens4	Sens5	Sens6	Sens7	Sens8
Sed_minerali_rt_NP (1/day)	2.4E-3 (a); 1.0E-1 (b)	-	-	-	-	-	-	-
Nit_Dnit_rt g N/(m <sup>3</sup> day)	-	84 (a); 0.84 (b)	-	-	-	-	-	-
NO3_penet_rt (1/day)	-	-	5.0E-1 (a); 1.0E+0 (b)	-	-	-	-	-
Diffu_coef (m <sup>2</sup> /day)	-	-	-	2.4E-5 (a); 5.0E-4 (b)	-	-	-	-
Fe_Psor_dsor (g P/ gFe)	-	-	-	-	5.0E-3 (a); 1.0E-1 (b)	-	-	-
Fra_N_mineral./im- mob. (number)	-	-	-	-	-	1.0E-1 (a); 3.0E-1 (b)	-	-
Fra_P_mineral./im- mob. (number)	-	-	-	-	-	1.0E-2 (a); 1.0E-1 (b)	-	-
Oxygen_pene1 (m)	-	-	-	-	-	-	1.0E-3 (a); 1.0E-2 (b)	-
Oxygen_pene2 (m <sup>2</sup> /(g DO))	-	-	-	-	-	-	-	1.0E-2 (a); 1.0E-1 (b)



**Figure S2\_1** Taylor diagrams for TN parameter's sensitivity analysis  
 The concentrations are multiplied by 1000; *St* means station (Figure 1)  
*Sens* means sensitivity; *Ref* means *St1*; *Sens0* refers to the baseline simulation.

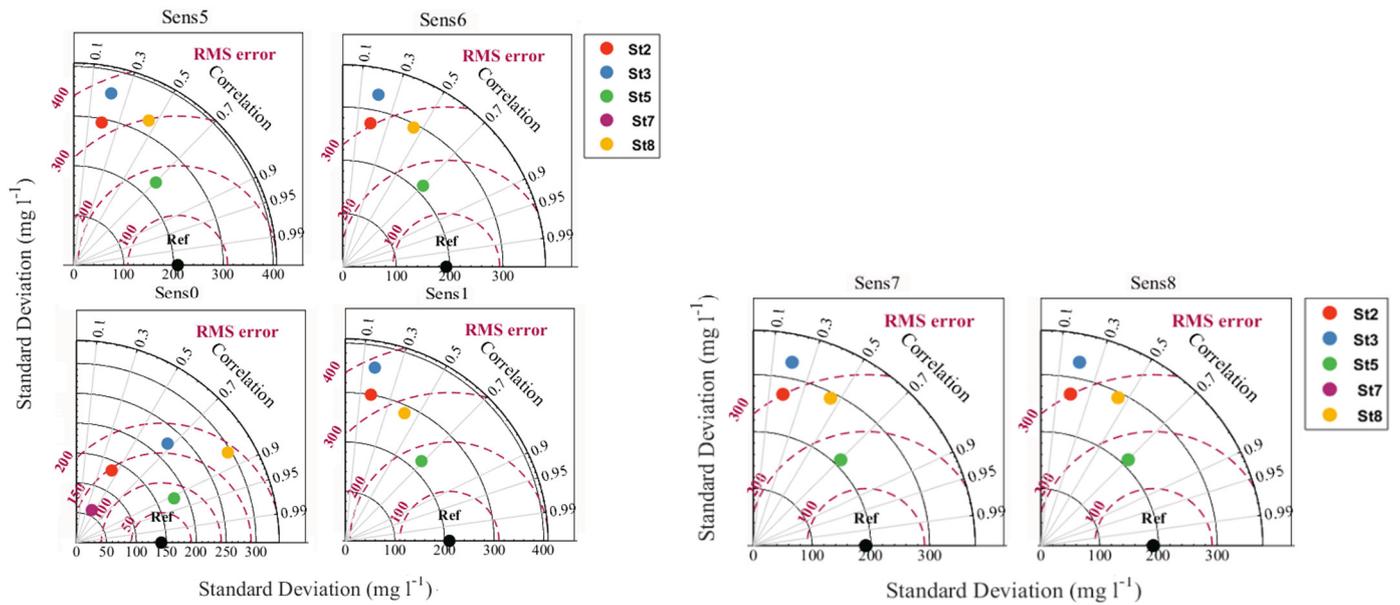


Figure S2\_2 Taylor diagrams for TP parameter's sensitivity analysis  
 The concentrations are multiplied by 10000; *St* means station (Figure 1)  
*Sens* means sensitivity; *Ref* means *St1*. *Sens0* refers to the baseline simulation.

Remarks:

Figures S2\_1 and S2\_2 plot the Taylor diagrams for the parameter's sensitivity analysis of Table S2\_2 and for five stations. Each plot is related to *St1*. The simulations are compared to the baseline *Sens0*, corresponding to a typical spring situation (average river flows). In the diagram, *Ref* refers to a reference station (*St1*).

*Sens4*, *6*, *7* and *8* present the highest *RMSE* values for *TN*, varying within the range of (0.1-0.3)  $\text{mg l}^{-1}$ , while *Sens0*, *1*, *2* and *3* the lowest, varying within (0.01-0.03)  $\text{mg l}^{-1}$ . Considering that *TN* typical mean values for *Sens0* are of the order of 0.3  $\text{mg l}^{-1}$ , it can be concluded that *Sens4*, *6*, *7* and *8* seem to be the most sensitive parameters for *TN*. When considering the stations influence, it seems like *St2*, *3* and *7* show the highest *RMSE* values, but, since *St8* is situated outside the diagrams, the last one corresponds, indeed, to the highest values. *TP* present low *RMSE* values for *Sens0* and *1* (<0.02)  $\text{mg l}^{-1}$ , while high for *Sens5*, *6*, *7* and *8* present relatively higher values ((0.02-0.03)  $\text{mg l}^{-1}$ ). Likewise, *St2*, *3*, *7* and *8* show the highest *RMSE* values. Considering that *TP* typical mean values for *Sens0* are of the order of 0.02  $\text{mg l}^{-1}$ , it can be concluded that *Sens4*, *6*, *7* and *8* seem to be the most sensitive parameters for *TN*.