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A prospective scenario for the Red River Delta at 2050 horizon

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ABSTRACT

Based on the use of the Seneque/Riverstrahler model, a prospective scenario of water quality has been developed based on expected demographic, land use and agricultural production changes in the Red River delta in northern Vietnam in order to evaluate the resulting changes in water pollution and nutrient loading delivered to the coastal zone at the horizon 2050.

The Vietnamese population is predicted to reach 112 million in 2050 with 57% that live in urban area. The amount of wastewater expressed in kg of suspended matter, N and P per inhabitant per day is estimated to decrease by about 10% in 2050 compared with current values. On the other hand, the wastewater discharge should increase twice, i.e. to 200 l/inhabitant/day. Besides, if the productivity of agriculture in the Red River Delta is to be nearly doubled in the future, this would likely result in a N surplus of about 150 kgN/ha/yr on the agricultural soils. Assuming the same leached fraction as currently observed, this would imply a mean leaching rate of 15 kgN/ha/yr, i.e. 3 times the present level.

By applying the above scenario to the Red River delta, our simulation shows that nutrient elements such as ammonium, phosphorus and silica seem to remain at the same concentration value. However, the concentration of these last elements will be largely on the dependence of the water volume due to the flood. Indeed, the delta floodplain improves largely the biogeochemical processes involved in the nutrient recycling. Our modelling results highlight that the Red River Delta system is already at its maximum of the nutrient recycling capacity.

So an increase of discharge from urban wastewaters and from agricultural intensification will lead immediately and definitely to an increase of the polluted waters in the hydrological system of the Nhue and Day Rivers, in spite of efforts in urban wastewater treatments.

Key words: *Red River delta, land use and agricultural production changes, modeling, nutrient export.*

1. Introduction

Nitrogen, phosphorous and silica are the three elements most likely to control the productive function of aquatic ecosystems. The nutrient loading of river systems in densely populated areas depends on a number of factors, including the hydrology, the inputs of material from land-based sources and the in-stream processes leading to transformation, retention and elimination of nutrients during their downstream travel through the river continuum. For a region such as the Red River Delta where river water quality has been dramatically deteriorated due to rapid population growth, industrialization and economic development in the recent years, a model must be built for assessing the significance of the complex and inter-related processes and understanding how river water quality and ecological functioning reflect the land-use and human activities in the watershed (Billen and Garnier, 1997).

The approach used in this study is based on the adaptation of the Riverstrahler model which has been developed in the framework of the PIREN-Seine program and some other international research programs (for the earliest references: Billen et al., 1994; Garnier et al., 1995) to relate the ecological and biogeochemical functioning of the whole drainage network of a large river system to the constraints set by the climate, the river system morphology and the human activities within its watershed. Beside the Seine River, this model has been successfully applied to the Mosel (France, Germany: Garnier et al., 1999), the Danube (Garnier et al., 2002), the Scheldt (Belgium: Billen et al., 2005) and the Red River (Vietnam: Le et al., 2010).

A large fraction of the total population of the Red River basin is settled in the delta area, especially on the right bank where the Hanoi city and conurbation is located. Therefore, we have chosen to implement the model on the right bank of the hydrological system of the delta, the Day-Nhue river system, and to connect it to the upper Red River model, in order to further understand the biogeochemical functioning of the delta system. Additionally, the aim was also to develop some scenarios based on expected demographic and land use changes in order to evaluate the resulting changes in water quality and nutrient loading delivered to the coastal zone at the horizon 2050. We also explored how the water flux of the upstream Red River could be better managed for possibly reducing the pollution of the Day River system by dilution.

2. The Red River Delta at 2050 horizon

2.1. Demographic trends

The trends of total and urban Vietnamese population since 1961 as documented from FAO statistics (FAOstat, 2010) is shown in Figure 1. The population increased from 34 millions in the beginning of the 1960's to 86 millions in 2009. Several studies have shown that the demographic transition, characterized by a reduction of mortality rates followed by a reduction of birth rates, is in progress since the 1970's and will result in a stabilization of the population within about one generation. Accordingly, FAO predicts a population of 105 millions inhabitants in 2030 and 112 millions in 2050. Still referring to FAO, the present urban population in Vietnam represents less than 30% of the total, but should reach 42% and 57% in 2030 and 2050 respectively (Figure 1).

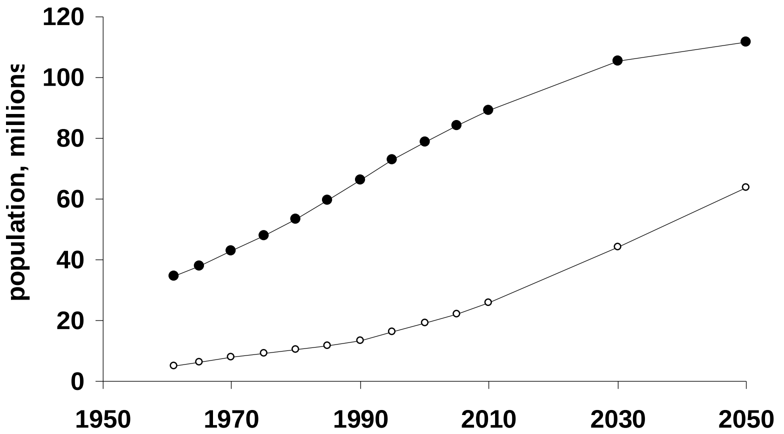


Figure 1: *Long term trends of total and urban population of Vietnam (FAO, 2010)*

More detailed studies available for the provinces of North Vietnam corresponding to the delta area confirm these estimates. A national inquiry on demography which has taken place in mid 2009 showed a 12% increase of population in the last 10 years (1999 to 2009) (General Statistical Office, 2009). The Red River Delta population should thus increase by a factor 1.3 by 2030 and a factor 1.4 by 2050. However, the increase in urban population is much more important than that in rural population (2.5 – 3% against 0.5 – 0.8%). In these rates, the immigration was considered. Each year, 0.7% of the rural population immigrated to both urban and another rural area and 0.22% of urban population immigrated to another urban area) but obviously, these rates of increase cannot be extrapolated over the next 50 years, since it is commonly accepted that the total population will stabilize. By considering a factor of 1.4 by 2050 for the total population together with the share in rural and urban population (57% of people live in urban area), we can predict the population of the Day River Basin in 2050 as shown in Table 1.

Table 1: *Population of the Day River Basin in 2006 and prediction for 2050*

		Urban	Rural	Total Day River Basin
2006		2 372 370	5 290 476	7 662 846
	%	*31.0*	*69.0*	
2050		6 114 950	4 613 034	10 727 984
	%	*57.0*	*43.0*	

2.2. Wastewater release

Using global data base assembled in the scope of the GlobalNEWS group, Seitzinger et al. (2010) and Van Drecht et al. (2009) estimated the present (2000) rate of population connection to a sewage system in the Red River watershed to about 6% (Table 2). This rate could reach 12 to 30% in 2030 and 15 to 36% in 2050 according to the scenarios of the Millenium Ecosystem Assessment (MEA). The treatment of the collected wastewater should remove 10 to 15% of the nitrogen load in 2030 and 16 to 28% in 2050.

Table 2: *Rate of population connection to a sewer system in the Red River watershed, and percent removal of the nitrogen load of collected sewage, according to Van Drecht et al. (2009) for 1970, 2000 and different prospective scenarios of the Millenium Ecosystem Assessment*

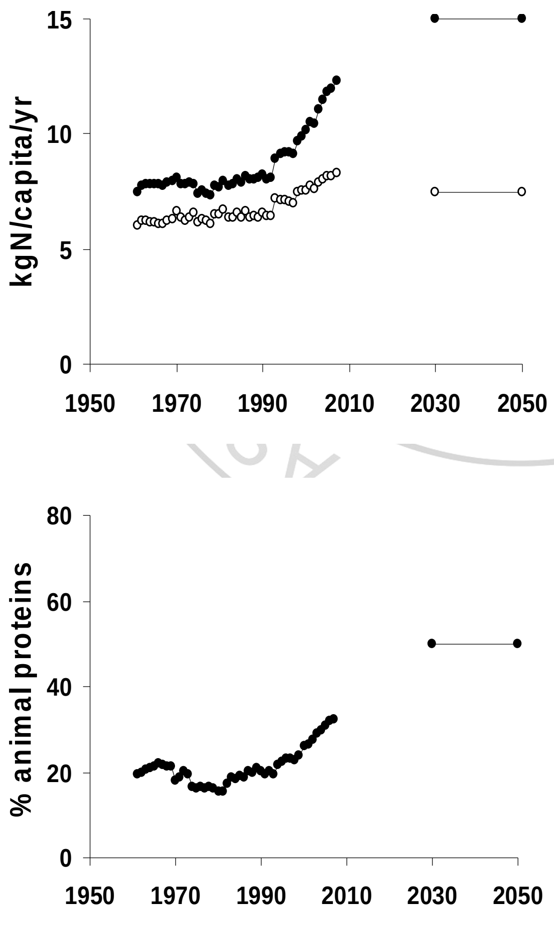
Year	Connection to a sewer system (% of population)	Nitrogen removal from collected sewage (% of collected load)
1970	1	0
2000	6	5.5
Global Orchestration 2030	12	14.5
2050	36	28
Adapting Mosaic 2030	11	10
2050	15	16
Techno Garden 2030	31	14.5

	2050	36	28

As there are no similar predictions by local authorities in North Vietnam, we used the figures provided by Van Drecht et al. (2009) for the calculation of 2050's scenarios. As a result, the amount of wastewater expressed in kg of SS, N and P per inhabitant per day is estimated to decrease by about 10% in 2050 compared with current values. On the other hand, the wastewater discharge should increase twice, i.e. to 200 l/inhabitant/day.

2.3. Agriculture

The predicted increase of total and urban population, as well as the documented increase in per capita food consumption of the Vietnamese population (Figure 2) will necessarily result in an increase of the productivity of the Vietnamese agriculture. Such an increase has already accompanied the previous population rise and is likely to continue in the future (Figure 3).



(a) (b)

***Figure 2:** Trends in the per capita food consumption of the Vietnamese population expressed in Nitrogen (protein) content; black points: total protein supply quantity, white points: vegetal products (a). Share of vegetal and animal products (past trends: FAO stat) (b)*

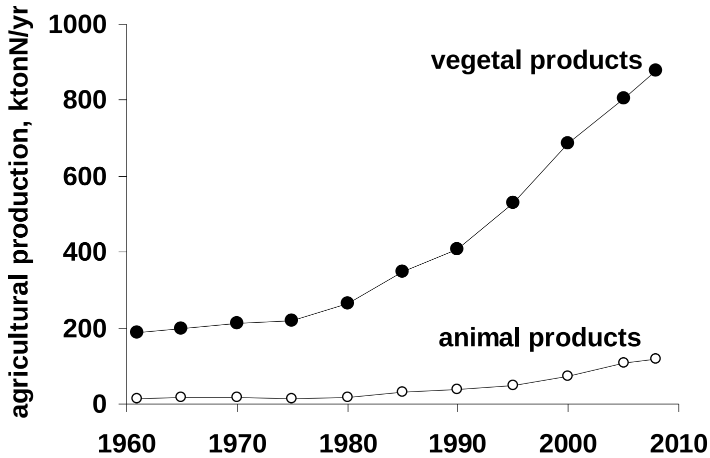


***Figure 3:** Trends in the production of Vietnamese agriculture (FAO stat), expressed in nitrogen content*

Taking into account the predicted population increase, the likely increase of total proteins consumption (Figure 2) as well as the increased of diet for animal production, a total increase of agricultural productivity within the Delta should be achieved in the order of 85% and 97% in 2030 and 2050 respectively. These estimates are based on the hypothesis of livestock conversion efficiency (kgN in fodder per kgN in animal products) of 20%, a percentage that the current Vietnamese animal farming is not far from reaching today.

2.4. Diffuse sources through nitrogen leaching

The data assembled by Luu et al. (2010) with respect to the nutrient budget of the Red River Delta offer the opportunity to calculate the nitrogen soil surface balance of agricultural areas, by comparing the total fertilization of agricultural land (through synthetic fertilizer and manure application, atmospheric nitrogen fixation by legume crops and atmospheric deposition) with the nitrogen content of harvested crops (Figure 4 and Table 3). The same calculations for the upper Red River sub-basins, based on the figures assembled by Le et al. (2005), show the much more intensive character of the agricultural practices in the Delta area (Table 3).

The N surplus calculated from these figures (excess N applied to the soils compared with the harvested N) represents the potential of nitrogen loss into the environment. Comparison with the estimated leaching rates, based on measured concentrations in small agricultural streams, shows that only a fraction of about 10% of this surplus reaches surface waters in the delta area, while this fraction is much higher in the upper Red River basins. It means the nitrogen excess is probably cumulated into the groundwaters.

On the basis of these estimations, if the productivity of agriculture in the Red River Delta is to be nearly doubled in the future, this would likely result in a N surplus of about 150 kgN/ha/yr on the agricultural soils. Assuming the same leached fraction as currently observed, this would imply a mean leaching rate of 15 kgN/ha/yr, i.e. 3 times the present level.

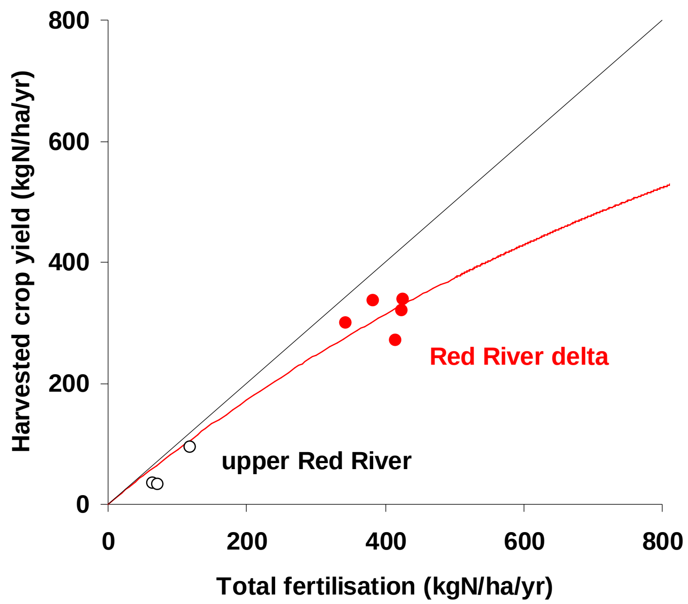


Figure 4: *Nitrogen soil surface balance in agricultural lands of the Red River Delta and the upper basin of the Red River (data from Luu et al. (2010, in press) and Le et al. (2005)*

Table 3: Nitrogen soil *surface balance in agricultural lands of the Red River Delta and the upper basin of Red River (data from Luu et al. (2010, in press) and Le et al. (2005). Calculation of the leaching rates*

	Bui-Day	**Boi**	**Day estu**	**Lower RR**	**Duong**	**Total RRD**	**RR Da**	**Lo**	**Thao**
Area (km²)	2751	2473	1413	4773	2902	**14312**	51285	61169	34559
SAU, km²	1260	504	722	2795	1346	**6627**	9795.435	20980.97	24329.536
10^6 kgN/yr									
Atmosph. Deposition on agr. areas	1.2	0.7	0.6	2.3	1.4	6.2	7	13	14
crop Nitrogen fixation	7.4	1.6	3	13.2	6	31.1	41	31	70
synthetic fertilizer application	24.4	9.7	13.7	56.6	27.6	132	26	36	31
livestock excretion	20.4	8.9	7.5	35.1	22.4	94.3	43	56	60
kgN/ha/yr									
total fertilisation	424	415	343	384	426	398	119	65	72
harvested crop yieldr	321	270	299	337	338	325	94	35	34
surplus	103	145	44	47	88	73	26	30	38
observed leaching to surface water	4.8	6.0	5.5	5.7	5.2	5.4	20	10	5
fraction of surplus	0.05	0.04	0.13	0.12	0.06	0.07	0.80	0.35	0.13

3. Results and discussions: prospective simulation at the 50 years horizon

The Seneque/Riverstrahler model has been run for two hypothetical “2050” scenarios based on the hydrological conditions of the year 2006 and by different changes as discussed above. For the first scenario, we suppose that there is no difference in wastewater treatment practices in 2050 compared to 2006, i.e. the same hypothesis concerning the release of wastewater in urban (no treatment and total release to surface waters) and rural areas (50% recycling in agriculture) has been made. For the second scenario, a water treatment is considered, following the estimates of Van Drecht et al. (2009) for his Global orchestration scenario (about 40% of total waste waters would be connected to sewage and the treatment would remove about 25% of nitrogen). For both cases, the wastewater discharge of 200 l/inhab/day is taken into account.

The results, presented in Figure 5, are contrasted in relationship with the part of the stream considered. A very important increase of nitrate is predicted only on the upper part of the Day River, while the other elements (ammonium and phosphorus) remain at the same concentration value. However, these last elements increase largely on the down part of the Day River and on the Nhue River. Then these simulations demonstrate that the current river system has already lost its capacity to purify the wastewaters. So an increase of discharge from urban wastewaters and from agricultural intensification will lead immediately and definitely to an increase of the polluted waters in the hydrological system of the Nhue and Day Rivers, in spite of efforts in urban wastewater treatments.

The calculated budgets for these two scenarios were compared with the budget calculated for the year 2006. The flux of nitrogen at the outlet of the basin is predicted to increase 3 or 2 fold according to the scenarios. The flux of phosphorus would increase by a lower rate, while the flux of silica would hardly change.

Based on these calculated nutrient fluxes, the ICEP (indicator of coastal eutrophication potential) (Billen and Garnier, 2007) has been calculated to assess the potential for new production of non-siliceous algae sustained by the riverine delivery. At the outlet of the Day River basin, the calculated N-ICEP shows increasing positive values, indicating that the amount of nitrogen already is, and will be more and more, in excess over the Si requirements for diatom growth, possibly leading to the development of non-siliceous, often harmful algal blooms. The P-ICEP is however negative in all scenarios, showing that there is no potential eutrophication concerning phosphorus.

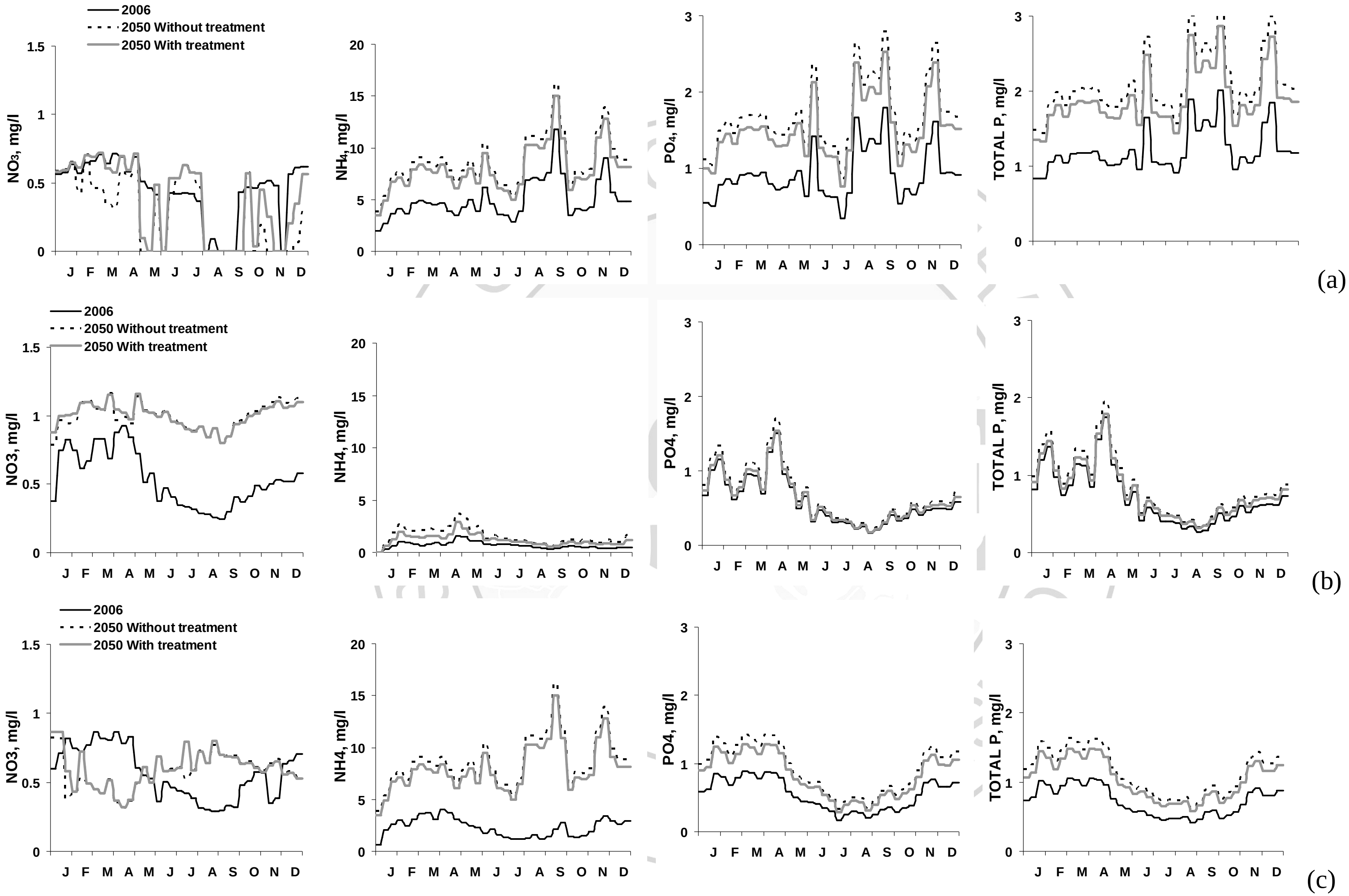


Figure 5: *Simulation results obtained at Nhue station (a), at Day upstream station (b) and at Day downstream station(c) for the '2050' and the 'reference 2006' scenarios*

Table 4: *Budget of N, P, Si for three different scenarios (2006 as reference, 2050 with domestic wastewater treatment and 2050 without domestic wastewater treatment) and values of N- ICEP and P-ICEP at the outlets of the Day River Basin for these respective scenarios*

	2006			2050 - Without treatment			2050 - With treatment		
	N (Kton/yr)	P (Kton/yr)	Si (Kton/yr)	N (Kton/yr)	P (Kton/yr)	Si (Kton/yr)	N (Kton/yr)	P (Kton/yr)	Si (Kton/yr)
Non-point sources	22.56	0.80	12.45	48.67	0.98	12.45	48.67	0.98	12.45
Point sources	23.62	6.09		43.68	12.07		39.62	10.86	
Entrance from Red River	2.40	0.68	9.79	3.37	0.83	9.89	3.37	0.83	9.89
Total inlet	***48.58***	***7.57***	***22.24***	***95.72***	***13.90***	***22.34***	***91.66***	***12.69***	***22.34***
Outlet	***16.16***	***4.03***	***21.13***	***35.08***	***6.82***	***22.08***	***31.78***	***6.24***	***22.08***
N-ICEP, gC/km²/yr		**14.03**			**60.27**			**51.99**	
P-ICEP, gC/km²/yr		**-16.38**			**-10.58**			**-12.03**	

4. Conclusions

The work presented here, which applies to the Day River Basin drainage network, shows the usefulness of the Seneque/Riverstrahler model for describing the ecological functioning of river systems. The model allows to describe the variations of water quality at the scale of the entire drainage network of the right bank of the Red River delta, in connection with the model of the upper Red River.

The model has been used to simulate a prospective scenario of the future state of the Day river system in 2050, as well as its future nutrient delivery to the coastal zone of the South China Sea. The ICEP calculated at the outlet of the basin highlights an increased risk for eutrophication in 2050 in spite of the implementation of urban wastewater treatment. Indeed the different simulations highlighted the Day River System is already at the threshold limit of its capacity to be able to accept the least increase of nitrogen (nitrate or ammonium) and phosphorus.

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