Hydrol. Earth Syst. Sci. Discuss., 4, S2281–S2294, 2008
www.hydrol-earth-syst-sci-discuss.net/4/S2281/2008/


Hydrology and Earth System Sciences Discussions



# *Interactive comment on* "Importance of stream temperature to climate change impact on water quality" *by* A. Ducharne

**A. Ducharne**

Received and published: 3 April 2008

First of all, the author wishes to thank the referee for his insightful comments, which were useful to improve the manuscript. A detailed answer is provided below.

This paper covers a predictive assessment of the impact of climate change on the runoff/ discharge as well as the water temperature at selected pairs of air/water monitoring stations, and the relationship of these inputs on water quality output obtained via the model RIVERSTRAHLER, exemplified within the River Seine Basin, France, and due to polluting point source discharges as they existed in 1991, and as predicted for 2050. Based on these remarks I propose to rename the title of the paper as follows: "Predicted impact of climate change induced discharges and stream temperature on water quality under differently polluting emissions".

ANSWER: I do not agree with this suggestion. A paper has already been published about the complex controls of the future evolution of water quality when both climate and pollution emissions are changing (Ducharne et al., 2007). As clearly indicated in the Introduction, the present paper focuses on the role of water temperature in this network of controls, and on the way water temperature change can be accounted for in the modelling. Had the title to be changed, it would be to better stress this.

The paper is well structured and in principle well discussed. Its novelty is the type of "integrated approach" as presented above, based on modelling procedures already in use or as shown in this paper. A. Ducharne is aware of the fact that the method derived for the prediction of water temperature fits within the context of the River Seine Basin (particularly starting with Paris and downstream), but differing results may emerge if the underlying statistically derived approach is applied in differently structured river basins. I subscribe to the view that basin shapes, the slopes of the river network and thus the speed of flow, as well as the sequences of river orders along the main rivers may influence respective outcomes.

The existing polluting discharges downstream of Paris and upstream of Conflans are since 2007 lower compared with the ones underlying the modelling work (in A. Ducharne et al., 2007) for 1991 in the frame of the PIREN-Seine Programme, see e.g. the web-pages of SIAAP (Syndicat Interdépartemental pour l'Assainissement de l'Agglomération Parisienne), http://www.siaap.fr/. Valid for the date of 2007/12/07 with values averaged over all days of the year 2007 for all plants of SIAAP – "full carbon removal" (in the sense that the quickly biodegradable carbon is removed) is installed, and efficiencies for nitrification and the removal of total phosphorus amount to _ 75%. For the treatment plant Paris-Achères (Seine Aval) downstream of Paris – treating ca. 75% of the wastewater of all plants of SIAAP – the respective values are 72% for P-removal and 63% for nitrification. One has to be aware of, however, that these values are still substantially larger than the ones anticipated for the year 2050 in the underlying simulation work (A. Ducharne et al., 2007).



HESSD

4, S2281–S2294, 2008

ANSWER: You are right. In Ducharne et al. (2007) and in the present paper, the baseline period is 1985-1991, to prevent as much as possible from climate change influence (remember that the 1990's decade was the warmer ever recorded). In the reference simulation, we thus used point-source pollution of 1991. The related point sources are higher than the ones postulated for 2050, as illustrated for ammonium in Paris and Conflans when comparing Figures 8 and 9. But these point-sources are also higher than the ones of 2000, with the exception of nitrate. This is clarified in the text, in section 6.1, as following: "Simulation IWT differs from ACT by the point-source inputs to the streams, which are assumed to be reduced. As detailed in Ducharne et al. (2007), future point source pollution by 2050, of both domestic and industrial origin, was estimated following the assumptions embedded in scenario SRES-A2 regarding demographic, economic and technologic changes. This led to reductions of 30 to 75% compared to 2000, depending on the pollutants. The technology efficiency, as estimated for 2050 from specialised technological prospective and experts interviews, was found to be the primary driver of this evolution. This scenario is a "business as usual" scenario as it follows the current trend to improved wastewater collection and treatment. This trend was already ongoing between 1991 and 2000, with the exception of nitrate. Overall, all point-source pollutants are reduced by more than 75% between simulation ACT, for "Actual (1991) point sources", and simulation IWT, for "Improved Wastewater Treatment". This reduction in point source inputs is also the only difference between simulations IWT+A2 and IWT+A2-Tw on the one hand, and simulations ACT+A2 and ACT+A2-Tw on the other hand."

The in-stream parameters used (inter alia for describing "water quality") are flow and water temperature, plus chlorophyll-a, dissolved oxygen, phosphate and ammonium; silica is unfortunately missing, if available to be added in Fig. 2.

ANSWER: Note that the simulated in-stream parameters are more numerous than the ones listed above, as explained p2430. To highlight this, the number of simulated variables is added in the text: "Unless otherwise mentioned, water quality in the rest of



HESSD

4, S2281–S2294, 2008



the paper will be used as a surrogate for the ensemble of 23 state variables simulated by RIVERSTRAHLER within the entire river network. They comprise the concentrations of oxygen, nutrients (NH4+, NO3-, PO43-, particulate inorganic phosphorus and SiO2), suspended solids and organic carbon (particulate and dissolved under three classes of biodegradability). Other state variables quantify the biomass (in mgC.l-1) of the main planktonic pools, with [etc.]" Regarding Figure 2, which provides the validation of the modelling tool in 1986-1990, it is unfortunately impossible to include dissolved silica, as this parameter is not monitored in Paris nor in Conflans nor in nearby stations. The reader is sent to Ducharne et al. (2007) for validation of this parameter at the outlet of the basin: "In particular, this work shows the good performance of the model to reproduce dissolved silica concentrations, which cannot be assessed in Paris and Conflans by lack of observations." In a general attempt to improve the discussion about the "organic matter", the validation was extended to dissolved organic carbon in Figure 2. The following sentences are introduced in section 3.3: "As in the rest of the paper, organic carbon is illustrated by dissolved organic carbon (DOC). It is slightly overestimated by RIVERSTRAHLER, but this model realistically simulates that DOC is mainly non biodegradable (70% in Paris and 60% in Conflans) and that it comprises two thirds of total organic carbon." Note also that the term "organic matter" was changed everywhere to "organic carbon", which describes precisely what is simulated by the RIVERSTRAHLER model.

The monitoring results presented are based on a calibration (see Fig. 2). The results predicted for 2050 are presented in the Figs. 8 and 9 (silica is contained, phosphate is missing). Fig. 7 presents the predicted change in discharge and water temperature, based on underlying climate change scenarios for the year 2050. An independent verification run of the modelling approach is not presented.

ANSWER: At least in this modelling exercise, phosphate behaves very much as ammonium with respect to improved water treatment and climate change, and it is not shown in Figs 8 and 9 to prevent them from being too heavy. The response of ammonium is



HESSD

4, S2281–S2294, 2008

also representative of the one of organic carbon. This is reformulated in section 6.2, p2444: "In both Figures 8 and 9, the changes in ammonium concentration are representative of the ones undergone by the point source effluents from the WTPs, including phosphate and organic carbon." More importantly, the simulated results shown on Figure 2 rely only feebly onto calibration, what justifies the title "Validation..." for section 3.3. All the parameters controlling the "water quality" evolution are set a priori from experimental determination (section 3.1), and most boundary conditions are prescribed from observations (river bed morphology, point sources, non-point sources deduced from land use, water temperature). The only exceptions are the diffuse sources of nitrate from agriculture and runoff, which are modelled using physically-based models, as they are likely to change significantly during the 21st century. Because of the focus on water temperature in this paper, I did not detail the assumptions behind the modelling of these terms, which are available in other papers (Ducharne et al., 2007; Ledoux et al., 2007). Regarding runoff, which is more discussed than nitrate in the present paper, it is modelled by the Catchment land surface model (CLSM, section 3.2). In this model, only three parameters are calibrated, namely the wilting point and the two parameters describing the vertical profile of saturated hydraulic conductivity, as explained in Ducharne et al. (2007). The numerous other parameters of this model, describing the various processes involved in the water and energy balance, are all set a priori based on the soil and vegetation properties, extracted from state-of-the-art data bases. As argued in Ducharne et al. (2007), we rely on physically-based models, with limited calibration, in order to guarantee, as much as possible, the transferability to situations that have never been experienced thus monitored. Of course, there is no way to verify this transferability, except by waiting a couple of decades. This is even worse regarding climate models, such as the one that underlies the climate change scenario used in this paper, as the validation of the climate change they simulate would require that the emissions of green-house gas and aerosols by the entire humankind followed one of the SRES scenarios... This discussion was summarized in section 3.2 "Modelling of runoff and diffuse nitrate sources". The fact that three parameters of CLSM



HESSD

4, S2281–S2294, 2008



are calibrated was added in section 3.3 "Validation in 1986-1990"

I am aware of the fact that the missing link to this is the period of time needed (at least one year, if not more) until new circumstances – as mentioned before – have allowed the assessment of data that can be used for a verification run. In regard to this aspect I am eagerly waiting until Mme. Ducharne will inform us anew what has been achieved in the years after the work for this paper was undertaken.

ANSWER: As mentioned in the conclusion section, an interesting validation would be a simulation in 2003, when point source pollution had already been markedly reduced compared to 1991, and with an exceptionally hot summer. This simulation, however, has not been done yet.

The main conclusion reached on the impact of climate change on water quality downstream of Paris is that substantially reduced polluting discharges will lead to usual concentrations of dissolved oxygen, the peaks of chlorophyll-a (riverine eutrophication) will be smaller compared with the discharge situation of 1991, and dissolved silica will still remain in solution, allowing the growth of diatoms in the Seine Estuary, and thus also improving the ecological status of the coastal waters of the River Seine Basin. The increased temperature due to climate change will only have a comparably small impact on water quality (with reference to the parameters chosen in the modelling approach). I imagine that these predictions are quite likely, but I can not actually prove them by an independent approach.

ANSWER: This comment sends back to the validation of the model, which is impossible as far as climate change is concerned, as already discussed above. An independent approach is possible, however, but using another model of riverine water quality. This certainly explains the popularity of intercomparison projects in the field of environmental modelling, and it would be a very interesting project in the well documented Seine River basin.

Interlude: What can we perceive as "water quality" and what is its relationship with



HESSD

4, S2281–S2294, 2008



waste water treatment? [...]

K. Wuhrmann also showed in his overview that in more shallow reaches of the river continuum all "self-purification processes" (like e.g. the removal of dissolved and particulate carbon and algal growth) are concentrated at the sediment-water interface, whereas with the increase in relative depth in large rivers the related biological transformations start to get dominant in single cells and flocs transported in suspension. As large rivers do not dominate in Switzerland, the work by Wuhrmann and his colleagues centred more on shallow streams. Wuhrmann concluded in his overview also that predation can be a very dominant loss factor, and that growth rates of primary biomass producers may be heavily biased by herbivores.

ANSWER: As mentioned in section 3.1, benthic mineralization is simulated by RIVER-STRAHLER, following Billen et al., 1989. Periphyton and biofilms, however, are not accounted for. The importance of this biologic pool on carbon and nitrogen budget has been studied in a headwater stream within the Seine basin by Flipo et al. (2004), using modelling to upscale the field and experimental results to the 40-km studied stretch. This work indicates that the main impacts of periphyton on the biogeochemical functioning of this shallow stretch is (i) an additional nitrification within the biofilm, which explains a decrease of ammonium concentration from upstream to downstream, and (ii) an increase in DOC export from the stretch. These impacts are significant at the scale of such shallow streams, as already widely reported in the literature, but they become negligible in larger streams, as :

- the local conditions are less favourable to periphyton development,

- the relative importance of planktonic biomass becomes dominant when the river depth increases,

- human concentration thus point-source inputs tend to increase and become dominant in terms of COD and ammonium.



HESSD

4, S2281–S2294, 2008

As for non planktonic species, the version of RIVERSTRAHLER used in the present paper only describes benthic filters, in a very simplified manner. The role of macrophytes has been studied in the Seine River basin, showing that headwater streams, where primary production is dominated by macrophytes and periphyton, collectively contribute for only a small fraction of the total net primary production of the basin, in spite of a total surface similar to that of the lower sectors (Billen et al., 2007).

The EU Water Framework Directive (2000/60/EC) is strongly based on status assessment of biological quality elements (phytoplankton; macrophytes and phytobenthos; benthic invertebrate fauna; fish fauna), and is in addition also considering hydromorphological quality elements and physico-chemical quality elements. Among these quality elements fish fauna is the one most likely to be impacted by changes in temperature.

ANSWER: You are perfectly right, and I tried to clarify the more restrictive definition of water quality that is used in the present paper. It focuses on the parameters simulated by the RIVERSTRAHLER model, that are clearly defined in section 3.1, and which together define what can be summarized as "biogeochemical water quality". I changed the text in many places to be more specific. In particular, I added the following sentences in the Introduction: "Water quality can also be impacted, through its many facets (physical, including temperature and turbidity; chemical, including pH and concentrations; biological, including biodiversity and species abundance, across the entire food web from microbial pools and macrophytes up to fishes). Focus is put on the so-called biogeochemical water quality, defined by the in-stream concentrations of nutrient, organic matter and oxygen on the one hand, and of the planktonic biological pools on the other hand, which combine for instance to control eutrophication."

Conclusions to the General Comments [...]

Specific Comments

2430:16 Sorry, I am having a certain problem with the sentence "Thus, the spatial-temporal variations of water quality are only controlled by the boundary conditions of



HESSD

4, S2281–S2294, 2008



the river network". This sentence is "true" in the sense that the term "water quality" is only determined by the contents of the RIVERSTRAHLER model (including the living species it describes), but for sure in contradiction with a concept of "water quality" in line with the existing resp. the aimed-at ecological status as defined in the EU Water Framework Directive. I thus am suggesting to Mme. Ducharne to explain more precisely what she means.

ANSWER: I meant water quality in the sense of the parameters simulated by RIVERSTRAHLER. It has been specified at the beginning of the preceding paragraph: "Unless otherwise mentioned, water quality in the rest of the paper will be used as a surrogate term for the ensemble of 23 biogeochemical variables simulated by RIVERSTRAHLER within the entire river network." The incriminated sentence was also changed to: "Thus, the spatial-temporal variations of the simulated biogeochemical water quality are only controlled by the boundary conditions of the river network."

2433:22 and further on "organic matter". Reference is made to this term (which is, as presented in the paper, a parameter of the RIVERSTRAHLER in-stream water quality model composed of several fractions, and by the same token also one of the "faces" of polluting discharges from SIAAP); unfortunately Fig. 2 contains no actual information on this parameter (in-stream).

ANSWER: "Organic matter" was replaced everywhere by "organic carbon". As mentioned in section 3.1, the latter is subdivided by RIVERSTRAHLER into particulate and dissolved organic carbon, each with three classes of biodegradability. Organic carbon is illustrated in the article by dissolved organic carbon (DOC). RIVERSTRAHLER slightly overestimates this fraction (see Fig. 2 updated), but it realistically simulates that DOC is mainly non biodegradable (70% in Paris and 60% in Conflans) and that it amounts to two thirds of total organic carbon.

In respect to "organic matter", see also 2433:28; 2442:10 ("organic matter" is cited; no data on polluting discharges at present contained in Table 2); 2443:28 (here I agree);



HESSD

4, S2281–S2294, 2008

2444:02 ("organic matter" is again cited, no actual data contained in Fig. 8); 2444:07 same situation; 2445:08 same situation, no data contained in Fig. 9; 2445:13 same situation; 2447:02 evidence in the paper based on data missing / in actual practice existing – or existed in the past – depending on the actual discharges in 1991.

ANSWER: As already stated, the response of ammonium with respect to improved water treatment and climate change is representative of the one of organic carbon. I checked this on the simulation results, but I did not add the corresponding panel Figs 8 and 9 to prevent them from being too heavy. This is now specified in section 6.2, p2444: "In both Figures 8 and 9, the changes in ammonium concentration are representative of the ones undergone by the point source effluents from the WTPs, including phosphate and organic carbon."

Additional remarks on "organic matter" and its interplay with "water quality":

The overview paper by K. Wuhrmann already cited discusses the issue of "organic matter" in its Chapter 5 in an indirect way. He showed that "organic matter" per se as an input to a river – and as also contained in the RIVERSTRAHLER model – can be utilized at strongly differing speeds (e.g. dry-fall of leaves or branches in clean streams decompose in much more slowly than downstream of the outfall of an un-treated wastewater discharge), and that a differentiation is needed. I further hint at the fact that industrial / trade waste discharges could also contain slowly decomposable and refractory organic substances.

ANSWER: You are perfectly correct.

[...]

Proposed solution to "organic matter":

I am asking Mme. Ducharne to properly check what she intends to explain with the term "organic matter&" in case she uses it, and to also supplement data in Figures / Tables if needed. The preceding remarks can hopefully be a certain guidance.



HESSD

4, S2281–S2294, 2008

ANSWER: This effort has been attempted, as explained in several instances above.

2442 and Table 2: The polluting point source discharges on which the calculations are based are mentioned in overview (see also Table 2); a full readability of the paper as a stand-alone publication is only assured if more details to the polluting discharges are highlighted, similar to the paper by A. Ducharne et al., 2007.

ANSWER: As mentioned above, I added the following in section 6.1: "Overall, all point-source pollutants are reduced by more than 75% between simulation ACT, for "Actual (1991) point sources", and simulation IWT, for "Improved Wastewater Treatment"

2444:18, 2444:20 and 2444:28 I propose to speak about "loss rate&" or "loss factors", and not about "mortality&". I do so with reference to the overview paper by Wuhrmann.

ANSWER: Done.

2445:12 Reference is made to nutrient limitation, but no evidence is shown in Figs. 8 and 9. Based on the work by Wuhrmann the question remains open whether e.g. phosphate is actually limiting. My asking to Mme. Ducharne is to actually prove the statement.

ANSWER: The advantage of models arises from their simplification of reality. In the present case, nutrient limitation is effective in the RIVERSTRAHLER model because the model was designed to this end. In absence of other changes, it is the only possible explanation to the decrease of phytoplankton biomass. Of course, it does not prove that such limitation would be effective in real conditions, with a more complex interaction of driving factors. As in all modelling exercises, what gives confidence in the realism of the simulated response is:

- the fact that each individual process is formulated according to kinetics that were validated against field or experimental data;

- the validation of the model as a whole, as discussed above.



HESSD

4, S2281–S2294, 2008

2446:23 to 28 If Mme. Ducharne agrees I propose the following text for this part of the paper: "The simulated results highlight how water quality as modelled is driven by three factors, namely river discharge, water temperature and inputs to the river network. The existence of species that relate to water quality as modelled, and their complex interaction with their environment lead to this result. The underlying evolution is strongly determined by human activities, either directly or indirectly (e.g. climate change)."

ANSWER: The following change was preferred: "The evolution of the biogeochemical water quality simulated by RIVERSTRAHLER is shown to result from complex interactions between these three factors, the evolution of which are all controlled by human activities, either directly or indirectly (e.g. climate change)." I also opened the conclusion to the other aspects of water quality, at the very end of section 7: "The proposed model of water temperature could as well be used to explore the impact of climate change on other aspects of water quality. In particular, ample evidence has now been gathered about ongoing changes in the structure of riverine ecosystems that can be attributed to the premises of climate change (e.g. Daufresne and Boet, 2007). Modelling would permit to propagate these trends to the future, as already attempted by Eaton and Scheller (1996) for instance, who found that climate warming could reduce the habitat of both cool and warm water fishes."

Editorial proposals

Proposed rephrasing / new wording in italics; deletions no longer shown.

ANSWER: All done except otherwise mentioned.

2444:22 ..... , which take dissolved silica up as a nutrient. .....

ANSWER: Apparently, the correct phrasing is "which take up dissolved silica"

In Chapter 7 please use the present tense instead of the past tense, i.e.

2447:05 ..... discharge changes are higher .....



HESSD

4, S2281–S2294, 2008

Interactive Comment



ANSWER: "were" is preferred in this conditional sentence.

Cited references

Billen, G., Dessery S., Lancelot C., Meybeck M., 1989. Seasonal and interannual variations of nitrogen diagenesis in the sediment of a recently impounded basin. Biogeochemistry, 8: 73- 100.

Billen, G., Garnier, J., Mouchel, J.M., and Silvestre, M.: The Seine system: Introduction to a multidisciplinary approach of the functioning of a regional river system, Science of the Total Environment, 375, 1-12, doi:10.1016/j.scitotenv.2006.12.001, 2007.

Daufresne, M., and Boet, P.: Climate change impacts on structure and diversity of fish communities in rivers, Global Change Biology, 13, 2467–2478, doi: 10.1111/j.1365-2486.2007.01449.x, 2007.

Ducharne, A., Baubion, C., Beaudoin, N., Benoit, M., Billen, G., Brisson, N., Garnier, J., Kieken, H., Lebonvallet, S., Ledoux, E., Mary, B., Mignolet, C., Poux, X., Sauboua, E., Schott, C., Théry, S. and Viennot, P.: Long term prospective of the Seine River system: Confronting climatic and direct anthropogenic changes, Science of the Total Environment, 375, 292-311, doi:10.1016/j.scitotenv.2006.12.011, 2007.

Eaton, J.G., and Scheller, R.M.: Effects of Climate Warming on Fish Thermal Habitat in Streams of the United States, Limnology and Oceanography, 41(5): 1109-1115, 1996.

Flipo, N., Even, S., Poulin, M., Tusseau-Vuillemin, M.H., Ameziane, T., and Dauta, A.: Biogeochemical modelling at the river scale: plankton and periphyton dynamics Grand Morin case study, France, Ecological Modelling, 176, 333-347, doi:10.1016/j.ecolmodel.2004.01.012, 2004.

Ledoux, E., Gomez, E., Monget, J.M., Viavattene, C., Viennot, P., Ducharne, A., Benoit, M., Mignolet, C., Schott, C., and Mary B.: Agriculture and Groundwater Nitrate Contamination in the Seine Basin. The STICS-MODCOU modelling chain, Sci. Total Envir., 375, 33-47, doi:10.1016/j.scitotenv.2006.12.002, 2007.



HESSD

4, S2281–S2294, 2008

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 4, 2425, 2007.



HESSD

4, S2281–S2294, 2008

Interactive Comment