# Hydro-climatic response of Paris metropolitan area through TEB-Hydro model simulation: multi-catchment calibration and model evaluation

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## Highlights

- Development of a hydrological calibration method for a large multi-catchment urban area.
- Hydro-climatological evaluation of TEB-Hydro model
- Study of the hydro-climatic response of Paris urban area over 18 years

## Introduction

Both energetic and hydrological cycles are linked in cities. Indeed, evaporation of water stored in the soil or transpiration of vegetation can help reduce air temperature by consuming energy during phase changing. Nature Based Solutions, including Sustainable Urban Drainage Systems, rely partly on this process, which can both make urban drainage management more sustainable and improve outdoor thermal comfort. An in-depth understanding of the link between hydrology and climate is therefore essential for the adaptation of cities to climate change and for a more integrated urban water management.

Hydro-climatic models can be a tool to improve the knowledge on the processes linking urban drainage and microclimate. The TEB model (Town Energy Balance; Masson, 2000) is a precursor in this domain. This physics-based model was initially developed to simulate outdoor micro-climatic conditions in the urban environment from city to neighborhood scale. It now considers an urban subsoil, which can contain an urban sewer network (TEB-Hydro; Stavropulos-Laffaille et al., 2018), while representing explicitly herbaceous (TEB-Veg; Lemonsu et al., 2012) and tree urban vegetation (TEB-Tree; Redon et al., 2017; Redon et al., 2019). Both of these parameterizations have been evaluated in previous studies. Coupling these new parameterizations can improve the modelling of the physical processes associated with water and energy exchanges such as latent heat flux.

Due to a lack of data to perfectly initialise the model and the parameterizations that simplify the reality, a calibration process is generally needed. So far, TEB-Hydro has been calibrated on two independent catchments (Stavropulos-Laffaille et al., 2018). The particularity of our study domain is that it expands to an entire urban territory (>1000km2), which requires a multi-catchment approach, rarely applied in urban areas. This is consequently followed by an evaluation phase. Often carried out in a crossed way, in this study, calibration and evaluation periods don't overlap allowing a more robust and reliable evaluation. This is made possible by the availability of long hydrological observation records, and a long simulation period (18 years).

Hydro-climatology coupling is commonly studied in rural areas with a focus on global or regional scale. This study is one of the first to model in a coupled way the water cycle and the energy balance at a city scale thanks to TEB-Hydro latest improvements. Its purpose is both to improve understanding processes linking these budgets through simulation of the case study of the Paris urban area.

A modelling framework is defined in order to: firstly carry out a calibration and an evaluation of the study area based on a multi-catchments approach; secondly demonstrate how the application of this coupled model is useful to better understand the tight link between hydrological and energy budgets at the scale of an entire urban territory. This will allow for a more comprehensive modelling of the urban water cycle and thus the simulation of a more realistic hydro-climatic response of cities and ultimately of potential adaptation strategies.

# Methodology

Paris urban area is chosen as a case study. With the use of the TEB model, it is possible to reach a 250 m horizontal resolution over a 72 km by 72 km area. The simulation period extends from 2000 to 2018. Previous work has led to the reconstruction of a simplified, yet complex, urban sewer network throughout the study area (Chancibault et al., 2021). This sewer network is mainly composed of a combined system in the center of the area and a separate system at the periphery. Stavropulos-Laffaille et al. (2018) highlighted the parameters to which the model is the most sensitive and therefore required to be calibrated. These are the sewer pipe water tightness (IPsewer), the infiltration rate through the road (Iroad), the effective fraction of impervious surfaces connected to the sewer network (Connex), and the potential limitation of deep drainage (Urbdrain) which enables to increase soil water content since the model does not represent the saturated zone.

### Available data

In the studied area, measures of combined and storm water networks flows and overflows were collected. A qualification process relying on rain gauges and expert analysis has first taken place. Beforehand, the method for separating clear parasitic water and rainwater from waste water in the combined sewer flow measurements was applied. It makes it possible to compare observed and simulated discharges.

### Calibration of the model parameters

The wide studied area presents numerous catchments determined after the network reconstruction, allowing for a multi-catchment calibration. Based on gauged catchments holding sufficiently long records, a regionalisation method was developed in order to determine calibrated model parameters values for all the gauged and ungauged catchments over the domain. On the basis of gauged catchments, five hydrological classes were determined by the k-medoids clustering technique, relying on slope, sealing and type of sewer network of each catchment. This allows to assign a class to all catchments, including those ungauged (Figure 1) and consequently the hydrological characteristics representative of a specific class. An objective function is used to assess the optimize scores for each calibration configuration per class, relying on Nash Sutcliffe Efficiency and the percentage of bias, most recommended scores in hydrological calibration (Moriasi et al., 2007).

# Results and discussion

Following the calibration phase, the values of the calibrated parameters the most suitable for each class are determined (Table 1). At the scale of this study area, no difference is found between classes for sewer infiltration, little difference for urban drainage limitation, while road infiltration and fraction of impervious surfaces connected to sewer can vary greatly.

**Table 1.** Assigned calibrated parameters values by class.

| | Class 1 | Class 2 | Class 3 | Class 4 | Class 5 |
|---|---|---|---|---|---|
| Hydrological characteristics | High slope Low imper. Storm water | High slope Low imper. Combined | Low slope Low imper. Combined | Low slope Medium imper. Combined | Low slope High imper Combined |
| Urbdrain (-) | 0.00 | 0.02 | 0.00 | 0.02 | 0.00 |
| Iroad ($m.s^{-1}$) | 1E-3 | 1E-3 | 1E-3 | 1E-5 | 1E-5 |
| IPewer (-) | 10 | 10 | 10 | 10 | 10 |
| Connex (-) | 0.6 | 0.7 | 0.7 | 0.7 | 0.9 |

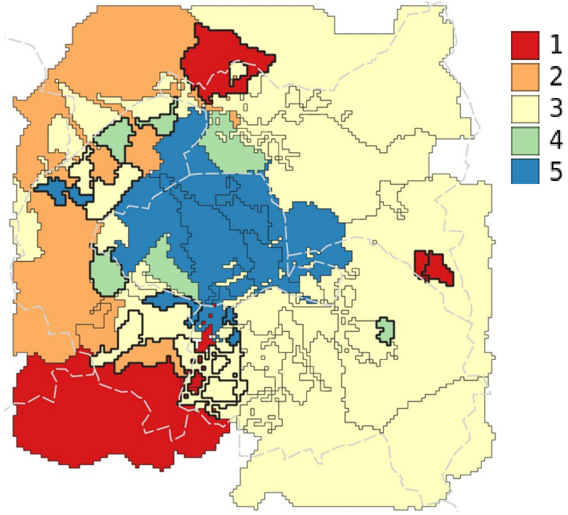


**Figure 1.** Delimitation of urban catchments and their hydrological class (colour scale, see Table 1 for details). Gauged catchments are delimited by thick black lines.

**Model evaluation**

The evaluation of the hydro-climatic diagnostics simulated by TEB-Hydro is pursued relying on water discharges and micrometeorological observations collected. This evaluation of the simulated flows is carried out on the same scores as the calibration on several catchment areas. It allows the assessment of the spatial and temporal coherence between model and observations during two periods of three consecutive years. This work will be presented in greater detail.

**Hydro-climatic response of Paris urban area**

This study allows a better understanding and characterization of this dense urban area with a simulation of 18 years while highlighting the impact of the urban hydrological cycle on microclimate such as the intensity of the urban heat island and conversely how climatic characteristics impact the urban water cycle (runoff, overflows, storage,...).

# Conclusions and future work

The multi-catchment calibration method allowed the best urban hydrological parameters to be refined for the studied area. This study illustrates the strengths and weaknesses of such a method, which is innovative when applied to an urban setting.

The hydro-climatic evaluation of the model is carried out in present time. Such a model can be useful to contribute to a more integrated urban water management and help study climate change impacts but also to evaluate climate change and urbanisation adaptation strategies of cities.

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