



Urbanisation, Climate Change and Stormwater Management Strategies: Modelling the Future Flow Regimes of Peri-Urban Streams in Lyon, France.

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Jeremie Bonneau, Flora Branger, Hélène Castebrunet, Gislain Lipeme Kouyi. Urbanisation, Climate Change and Stormwater Management Strategies: Modelling the Future Flow Regimes of Peri-Urban Streams in Lyon, France.. AGU Fall Meeting 2020, Dec 2020, San Francisco, United States. hal-03126926

HAL Id: hal-03126926


<https://hal.science/hal-03126926>

Submitted on 1 Feb 2021

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
Urbanisation, Climate Change and Stormwater Management Strategies: Modelling the Future Flow Regimes of Peri-Urban Streams in Lyon, France.



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Jeremie Bonneau, Flora Branger, Helene Castebrunet, Gislain Lipeme Kouyi

RiverLy - INRAE Lyon; DEEP - INSA Lyon



Introduction and goal

The health of peri-urban rivers is under pressure due to accelerating urbanisation and climate change. Predicting their flow regime is a less obvious challenge. We aim to model the hydrology of a peri-urban catchment located in the western suburbs of Lyon, France. We aim to study the response of the flow regime to:

- 1) future urbanisations
- 2) climate change
- 3) stormwater management scenarios, especially the implementation of green infrastructure that aims to mimic the natural water flows (infiltration, evapotranspiration).

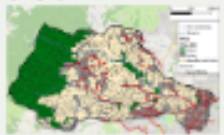
In this poster, we report the development of the model, the construction of scenarios and results of the calibration of the model.

Presentation and development of the model

Model used

In order to model the catchment and its stream, we used the hydrological model "2D500P" (Lalouin, 2013), a distributed, process-based model, a variant of 2D500 developed by the University of Jena in Germany (Krause, 2012), adapted to peri-urban catchments. The model runs at the hourly time-step.

The catchment was discretized in Hydrological Response Units (HRUs), homogeneous in landuse, soil cover and underlying geology (Figure below). Each HRU is then homogenized hydrologically.



With each HRU, 2D500P takes into account the following hydrological processes: interception of rainfall by the vegetation, evaporation and surface runoff, infiltration into a "surface-pore" and storage from which evapotranspiration is drawn and into a "large pore" soil storage which produces subsurface interflow and percolates from the soil to a groundwater store that produces baseflow. Flow is then divided into three components: surface runoff, interflow baseflow. HRUs are connected to each other or to the stream through topology. The model takes into account multiple change networks: natural river networks as well as drainage networks, with outlets out of the catchment.

Urbanisation and stormwater management scenarios

Future urbanisation scenarios

The urbanised imperviousness was increased 12% in 2038. The catchment is undergoing urbanisation, with suburbs covering landuse. Following the work of Castebrunet (2014), maps of future urbanisation were created (Figure below). Based on an expert panel judgment, local stakeholders, demographic trends and regulatory projections, the scenario for future urbanisation in 2038 was as realistic as possible. Several scenarios were considered as more spread out, acceleration of the trend, deceleration in land development spread. We discarded these maps to be used as input of the model.

Climate scenarios


We aim to study the adaptability of the catchment to future climate change. To do so, hourly time-series of precipitation are needed as input data for the model.

Future climate projections are available for the catchment through the French portal DRAC (<http://www.data.climat.fr/>), based on different greenhouse gases emissions and representative concentration pathways. However, these data are not directly usable in this study, since they are only available at the monthly or daily time-step, too coarse for a flow, temperature (rain catchment). In addition, climate projections tend to adequately represent meteorological phenomena which are important for hydrology scenarios and model parameters.

Therefore, we chose a bottom-up approach (Floquet, 2018), also called approach by


Catchment characteristics

The catchment is located in the western suburbs of Lyon, France. It is 20 km² and drains mixed landuse: ranging from forested areas (parks, forested and urban areas, downstream of the catchment (see Figure below)).



The catchment is a sub-catchment of the Saône

Preliminary results: calibrated model at Rattier flow station 2012 - 2018



Daily observed and simulated flow (m³/s/day) and summary table of performance

Model type	Flow index	Model index	Model index
Model type	Flow index	Model index	Model index
Model type	Flow index	Model index	Model index

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Jeremie Bonneau, Flora Branger, Helene Castebrunet, Gislain Lipeme Kouyi

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INTRODUCTION AND GOAL

The health of peri-urban rivers is under pressure due to accelerating urbanisation and climate change. Predicting their flow regime in a few decades is a challenge. We aim to model the hydrology of a peri-urban catchment located in the western suburbs of Lyon, France. We aim to study the response of the flow regime to:

1/ future urbanisation

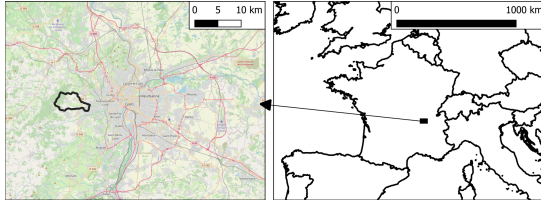
2/ climate change

3/ stormwater management scenarios, especially the implementation of green infrastructure that aims to mimic the natural water fluxes (infiltration, evapotranspiration)

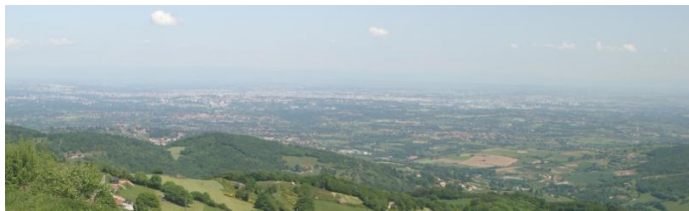
In this poster, we report the development of the model, the construction of scenarios and results of the calibration of the model.

CATCHMENT CHARACTERISTICS

The catchment is located in the western suburbs of Lyon, France. It is 20 km², and drains mixed landuse: ranging from forested areas upslope, farmland and urban areas downslope of the catchment (see Figure below).



The catchment is a sub-catchment of the Yzeron catchment, part of the long term observatory in Urban Hydrology OTHU (<http://www.graie.org/othu/> (<http://www.graie.org/othu/>))



From 1997 to 2019, the catchment averaged 716 mm of rainfall with an average potential evapotranspiration of 762 mm. The catchment is drained by a stream (le Ratier), that has been monitored for 10 years now. Catchment geology is uniform (metamorphic rocks), and soils are a range of shallow sandy-loams (1-3 m in average).

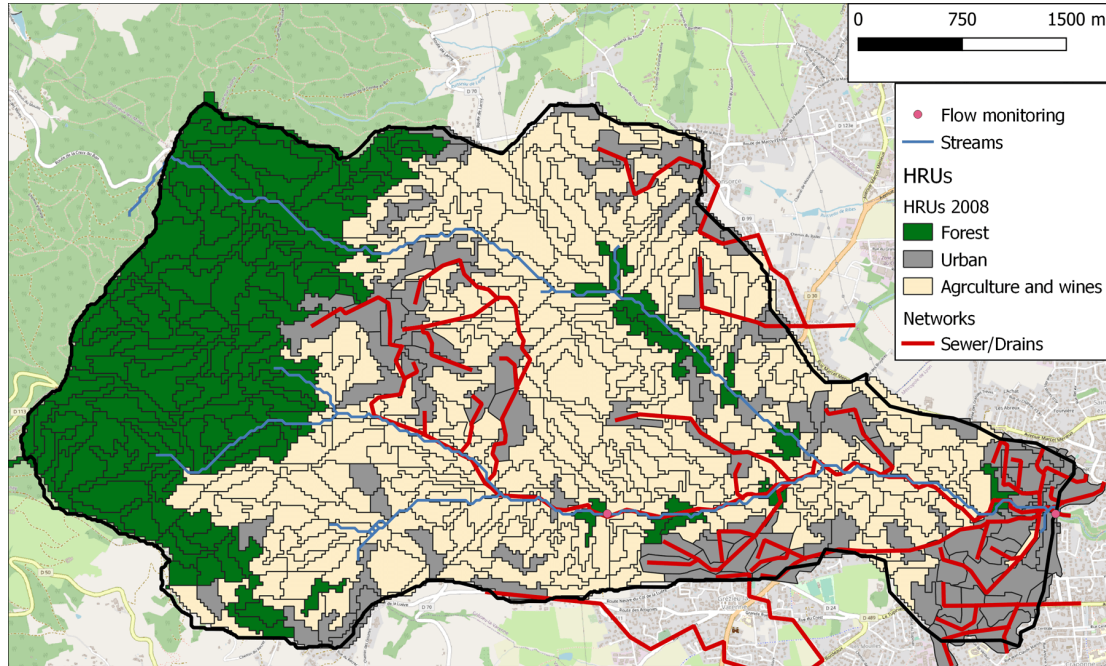
Stormwater in urban areas are drained by a combined stormwater/sewer network, meaning that most rainfall on impervious areas is collected and drained out of the catchment (except for occasional combined sewer overflow spills).

PRESENTATION AND DEVELOPMENT OF THE MODEL

Model used

In order to model the catchment and its stream, we used the hydrological model J2000P (Labbas, 2015), a distributed, process-based model, a variant of J2000, developed by the University of Jena in Germany (Krause, 2002), adapted to peri-urban catchment. The model runs at the hourly timestep.

The catchment was discretised in Hydrological Response Units (HRU), homogeneous in landuse, soil cover and underlying geology (Figure below). Each HRU is thus homogeneous hydrologically.



Within each HRU, J2000P takes into account the following hydrological processes: interception of rainfall by the vegetation, impervious and surface runoff, infiltration into a ‘medium pore’ soil storage from which evapotranspiration is drawn and into a ‘large pore’ soil storage which produce subsurface interflow and percolation from the soil to a groundwater store that produce baseflow. Flow is therefore divided into three components : surface runoff, interflow, baseflow. HRUs are connected to each other or to river reaches through topology. The model takes into account multiple drainage networks: natural river networks as well drainage/sewer networks with outlets out of the catchment; into the river networks and through sewer overflow devices.

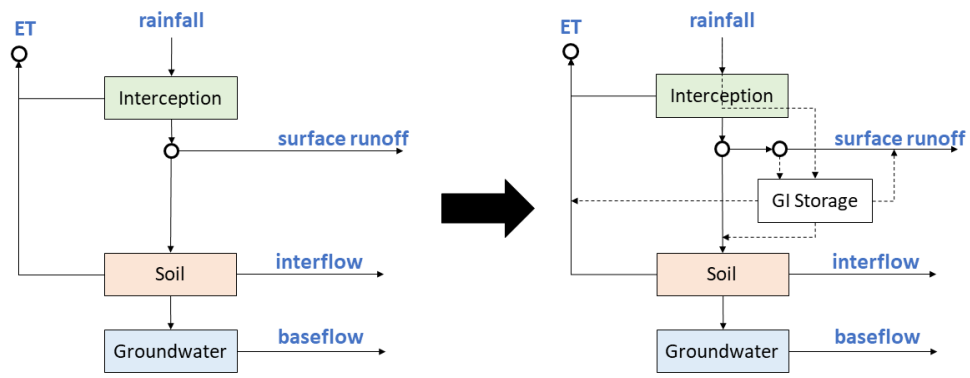
Input data

Rainfall data and flow data were source from the Hydrology Observatory Database Yzeron (Base de Données des Observatoires en Hydrologie, BDOH, <https://bdoh.irstea.fr/> (<https://bdoh.irstea.fr/>)).

Development of a green infrastructure model

We developed a Green Infrastructure module into the model to able to take into account systems such as infiltration trenches, green roofs, etc. Some of the surface runoff is diverted to green infrastructures (GI), that is either 1/ stored within the GI 2/ evapotranspired 3/ infiltrated into the native soil or 4/ connected back to the network.

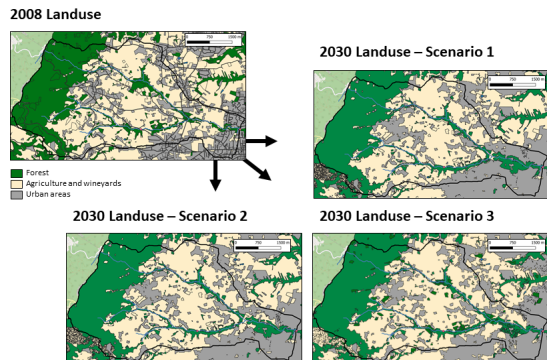
The Figure below presents a simplified conceptual diagram of the model with the addition of a green infrastructure module.



URBANISATION AND STORMWATER MANAGEMENT SCENARIOS

Future urbanisation scenarios

The catchment imperviousness was around 12% in 2008. The catchment is undergoing urbanisation, with suburbs covering farmland. Following the work of Dodanne (2014), maps of future urbanisation were sourced (Figure below). Based on an expert panel judgment, local stakeholders, demographic trends and regulations projections, the scenarios for future landuse in 2030 were as realistic as possible. Several scenarios were considered: current sprawl trend, acceleration of the trend, densification to limit the urban sprawl. We discretized these maps to be used as input of the model.



Future stormwater management scenarios

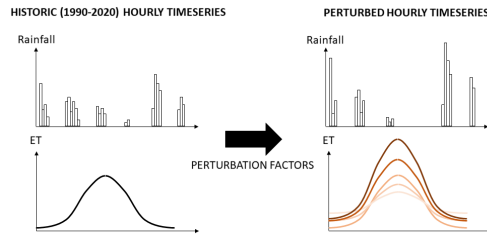
We are also setting up a range of stormwater management scenarios, with different degrees of 'disconnection' of newly impervious areas as well as some retrofit management scenarios in existing impervious areas. We estimated where it was possible and plausible to set up infiltration trenches, bioretention basins, green roofs, porous pavement, to manage runoff generated by impervious areas.

CLIMATE SCENARIOS

We aim to study the vulnerability of the catchment to future climate change. To do so, hourly timeseries of precipitation are needed as input data for the model.

Future climate projections are available for the catchment through the French portal DRIAS (<http://www.drias-climat.fr/>), based on different greenhouse gases emissions and representative concentration pathways. However, these data are not directly usable in this study, since they are only available at the monthly or daily timestep, too coarse for a fast, responsive urban catchment. In addition, climate projections fail to adequately represent convective meteorological processes which are important for subdaily storms and rainfall patterns.

Therefore, we chose a bottom-up approach (Sauquet 2019), also called approach 'by perturbation' to study the vulnerability of the catchment to climate change. We transformed present hourly timeseries (1990-2020) of rainfall and evapotranspiration by applying perturbation factors, to obtain future, hourly timeseries. The concept of the bottom-up approach is illustrated below:



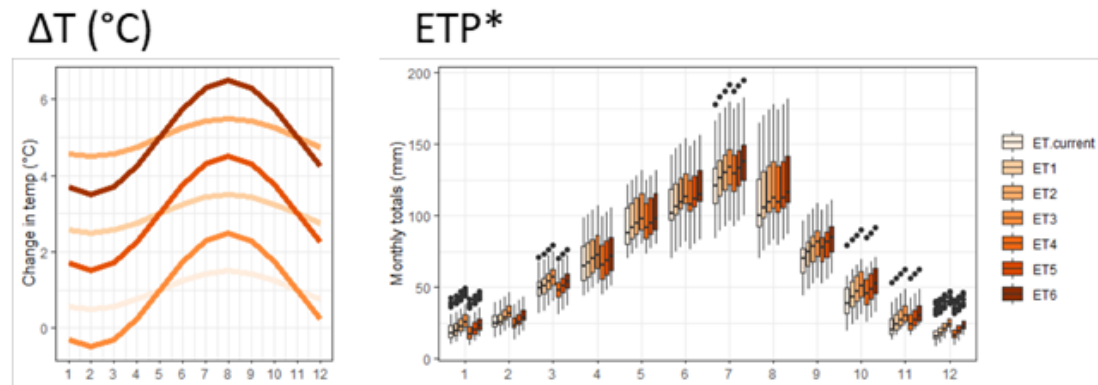
Evapotranspiration

Present evapotranspiration was transformed into six future evapotranspiration timeseries through six perturbations in the temperature regime, applied to the evapotranspiration timeseries with the Oudin formula (Oudin, 2005):

$$ETP_{hourly}^* = ETP_{hourly} + \frac{R_a}{28.5} \frac{\Delta T_{monthly}}{100}$$

With ETP* the new, perturbed evapotranspiration timeseries, ETP the current evapotranspiration timeseries, ΔT the monthly change in temperature, and R_a the catchment radiation (W/m²).

The change in monthly temperature ΔT (six scenarios) is modeled as a sine curve with varying annual mean increase +1, 3, 5 °C, annual amplitude of 0.5 or 1.5 °C, with a maximum change in August, as shown in the following Figure:



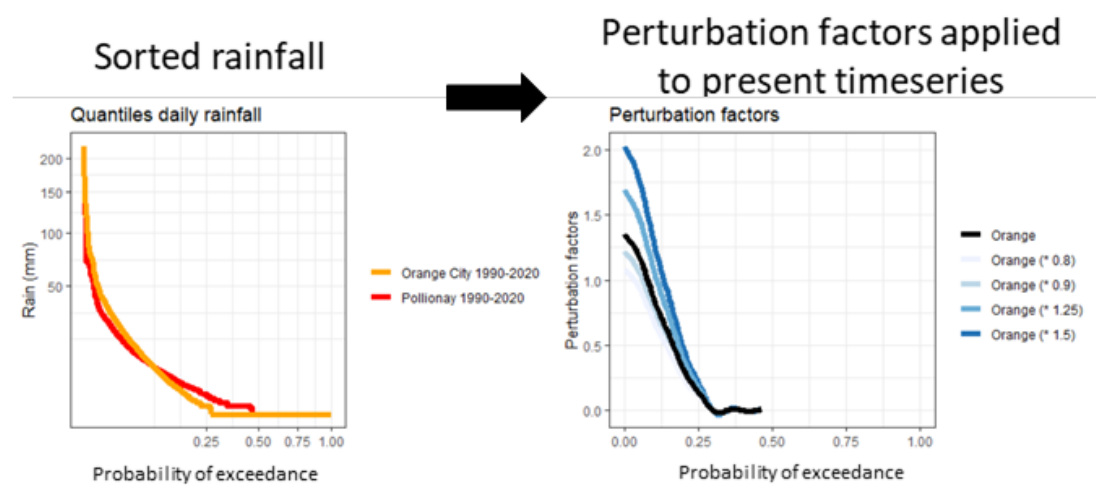
Rainfall

To create rainfall perturbation factors, we plotted probability of exceedance curves for daily rainfall for the catchment ("Pollionay") and for the southern French city of Orange (it is observed the climate in south easy France is drifting from south to North, with precipitation and temperatures in Lyon now looking like historical records of cities 50 km south). The perturbation factor was considered the quantile by quantile ratio, as:

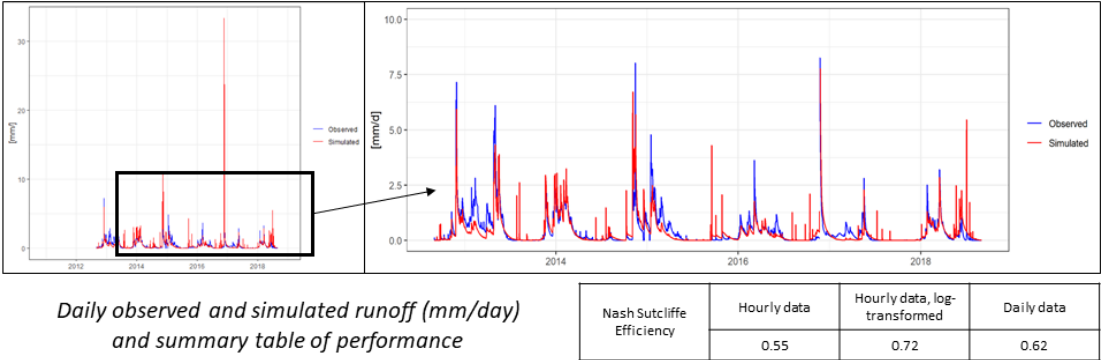
$$PF = \frac{p(q)_{future}}{p(q)_{present}}$$

with p daily precipitation corresponding to the quantile q.

Four perturbation factors were calculated as multiples of the initial perturbation factor calculated with Orange data (illustrated below). With these four perturbations, we take into account several possible increases of high rainfall and several possible changes in low rainfall patterns. These perturbations factors, calculated thanks to daily timeseries, are then applied to hourly present timeseries to obtain a range of possible future rainfall timeseries, to be used as input for the hydrological model.



Preliminary results : calibrated model at Ratier flow station 2012 - 2018



AUTHOR INFORMATION

Jeremie Bonneau¹, Flora Branger¹, Helene Castebrunet², Gislain Lipeme Kouyi²

¹RiverLy, INRAE Lyon, 5 Rue de la Doua, 69100 Villeurbanne, France

²DEEP, INSA Lyon, 11 Rue de la Physique, 69100 Villeurbanne, France

Contact: jeremie.bonneau@inrae.fr

ABSTRACT

The health of peri-urban rivers is under pressure due to accelerating urbanisation and climate change. Predicting their flow regime in a few decades is a challenge. We modelled the hydrology of two peri-urban catchments with the physically-based, spatially distributed hydrological model J2000P at the hourly timestep. We aimed to quantify the respective impact of 1/ real life scenarios of future urban development, 2/ climate change and 3/ potential stormwater management strategies ('disconnecting imperviousness') on the flow regimes of both rivers. We developed J2000P to integrate a site-scale model of green infrastructure. For several scenarios (combination of land use, climate, stormwater management scenarios), we looked at a range of hydrological signatures and metrics such as catchment water balance, baseflow behaviour, storm related metrics, combined-sewer overflows to calibrate the model and quantify the relative impact of landuse change, climate change and stormwater management. Preliminary results show that the model can be well calibrated to reproduce current flow regimes. Impending simulations will take into account future urbanisation scenarios and climate change characteristics, as well as disconnection strategies. Results will inform local public policies about the extent of green infrastructure implementation required to keep healthy rivers in the coming decades.

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Photo in 'Catchment characteristics' : <https://deims.org/cb1f4a9f-f6e3-4d2a-8b34-2f9c4c3f61b8>

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