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

**INRAE INSA deep** Urbanisation, Climate Change and Stormwater Management Strategies: Modelling the Future Flow Regimes of Peri-Urban Streams in Lyon, France.  
 Jérémie Bonneau, Flora Branger, Helène 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. Planning their flow regime in a few decades is a challenge. We aim to model the hydrology of a peri-urban catchment located in the urban 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 flows (detention, 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 "SWAP" (Lafont, 2012), a distributed, process-based model, a variant of SWAP developed by the University of Jena in Germany (Krause, 2002), adapted to peri-urban catchments. The model runs at the hourly time-step.

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

With each HRU, SWAP takes into account the following hydrological processes: interception of rainfall by the vegetation, evaporation and surface runoff, infiltration into a shallow zone and storage from which evapotranspiration is drawn and into a large zone and storage which produce subsurface interflow and percolates beneath soil to a groundwater store that produce baseflow. Flow is then split 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 scenarios: urbanisation scenarios as well as stormwater management, with outlets out of the

**Urbanisation and stormwater management scenarios**

**Future urbanisation scenarios**

The urbanised imperviousness was assumed 12% in 2020. The catchment is undergoing urbanisation, with suburbs covering half of the future urbanisation were assumed (Figure below). Based on an expert panel judgment, local stakeholders, demographic trends and regulatory projections, the scenario for future urbanisation in 2030 was set as realistic as possible. Several scenarios were considered: a) no spread, b) moderate, c) full, d) full, d) full, d) full. No detailed data were used as input of the model.

**Climate scenarios**

We aim to study the adaptability of the catchment to future climate change. To do so, four scenarios of precipitation are considered as input data for the model.

Future climate projections are available for the catchment through the French portal DRAM (<http://www.dram.cea.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, but not as for a flow, temperature or baseflow. In addition, climate projections tend to inadequately represent consecutive meteorological processes which are important for hydrology scenarios and model patterns.

Therefore, we chose a bootstrap approach (Boquet, 2018), also called approach by

**Climatic and hydrological characteristics**

The catchment is located in the urban suburbs of Lyon, France. It is 20 km<sup>2</sup> and distributed between ranging from forested areas (pines, beeches) and urban areas, downstream of the catchment (see Figure below).

The catchment is a sub-catchment of the Tassin

**Preliminary results: calibrated model at Rattier flow station 2012 - 2019**

Statistical	Observed	Simulated	Relative Error	Relative Error
Mean	0.22	0.15	0.23	0.32

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

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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

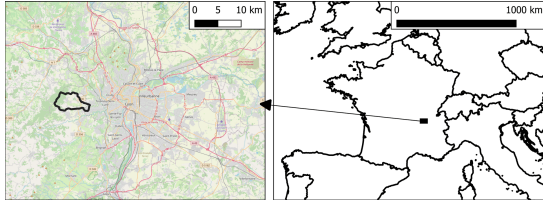
2/ climate change

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

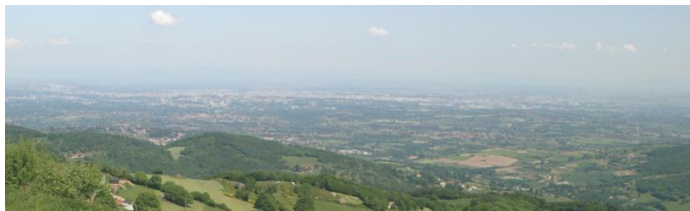
In this poster, we report the development of the model, the construction of scenarios and results of the calibration of the model.

# CATCHMENT CHARACTERISTICS

The catchment is located in the western suburbs of Lyon, France. It is 20 km<sup>2</sup>, 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).

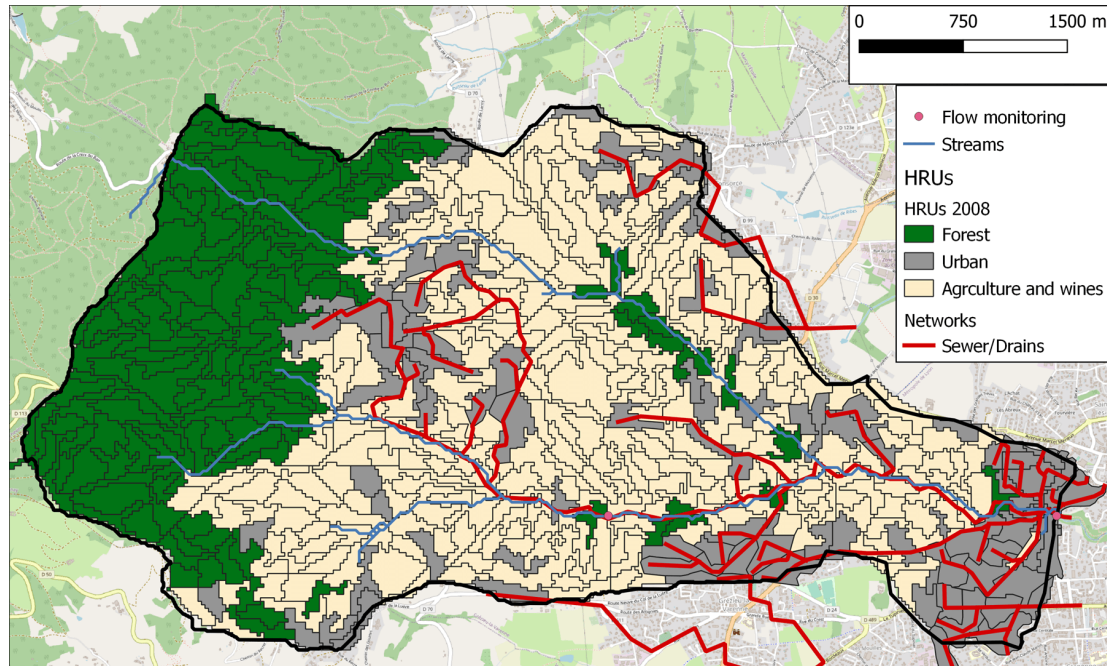
Stormwater in urban areas are drained by a combined stormwater/sewer network, meaning that most rainfall on impervious areas is collected and drained out of the catchment (except for occasional combined sewer overflow spills).

# 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.

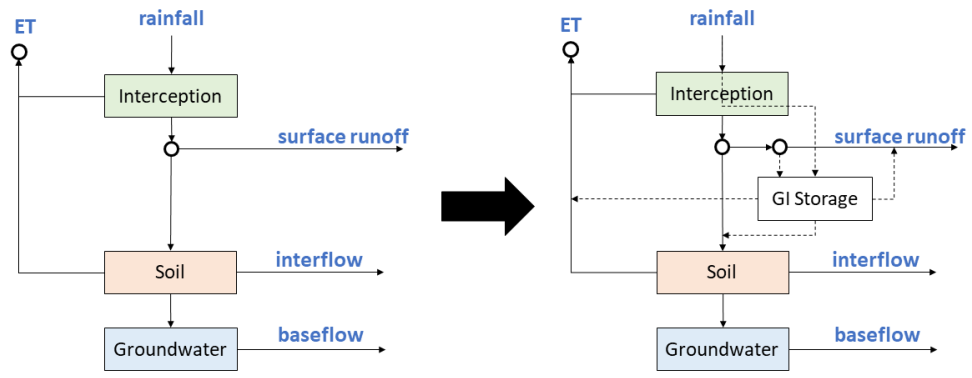
## Input data

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.

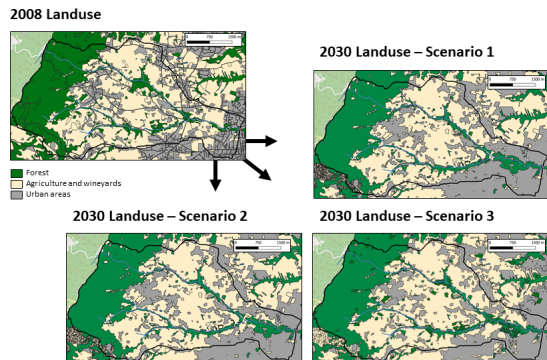
The Figure below presents a simplified conceptual diagram of the model with the addition of a green infrastructure module.



# 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

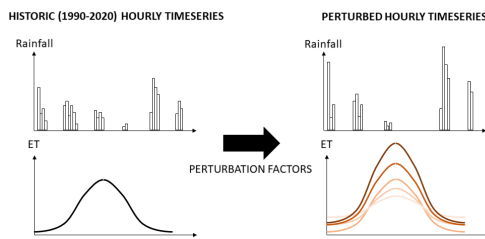
We are also setting up a range of stormwater management scenarios, with different degrees of 'disconnection' of newly impervious areas as well as some retrofit management scenarios in existing impervious areas. We estimated where it was possible and plausible to set up infiltration trenches, bioretention 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:



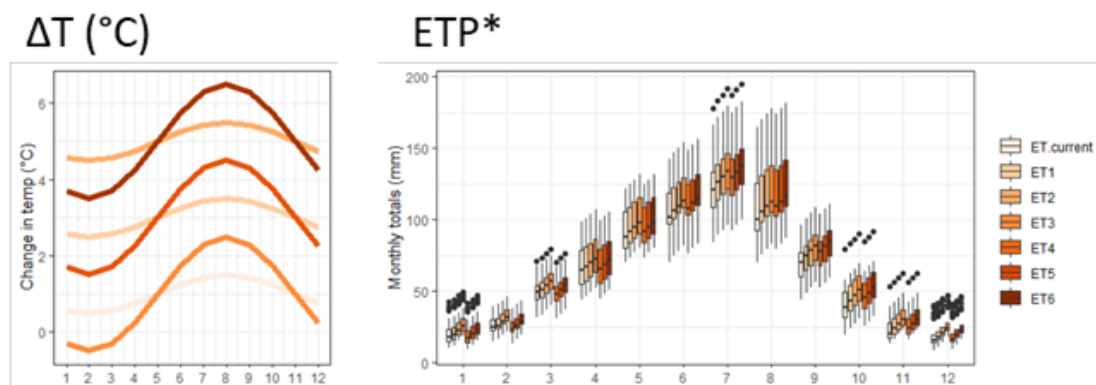
## Evapotranspiration

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,  $\Delta T$  the monthly change in temperature, and  $R_a$  the catchment radiation ( $W/m^2$ ).

The change in monthly temperature  $\Delta T$  (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

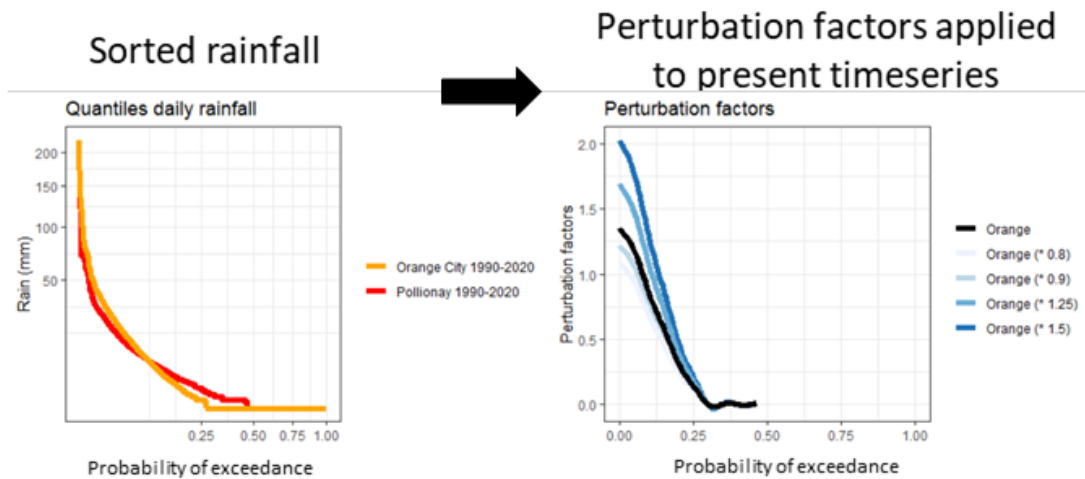
To create rainfall perturbation factors, we plotted probability of exceedance curves for daily rainfall for the catchment ("Pollionay") and for the southern French city of Orange (it is observed the climate in south easy France is drifting from south to North, with precipitation and temperatures in Lyon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

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

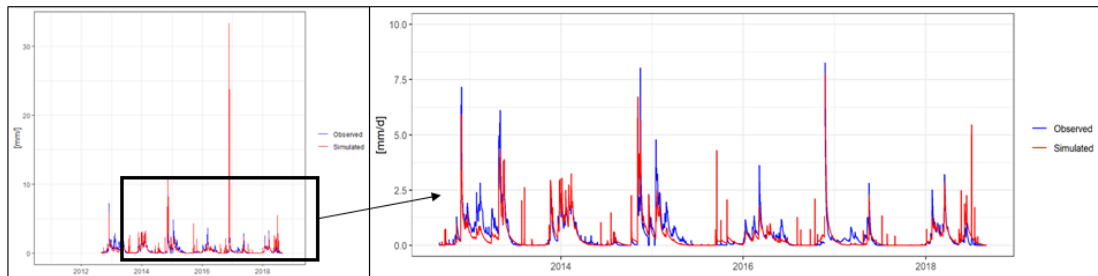
with  $p$  daily precipitation corresponding to the quantile  $q$ .



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**



*Daily observed and simulated runoff (mm/day) and summary table of performance*

Nash Sutcliffe Efficiency	Hourly data	Hourly data, log-transformed	Daily data
	0.55	0.72	0.62

# AUTHOR INFORMATION

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# 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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