

## AQUASUBURB: Quantification des temps de transit des débits de base en milieu péri-urbain

### AQUASUBURB: A quantification of transit times and subsurface flow paths of peri-urban baseflow

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#### RÉSUMÉ

L'impact de l'urbanisation et de l'imperméabilisation sur l'hydrologie des crues des rivières péri-urbaines est relativement bien connu : des débits de pointe plus marqués et plus fréquents. Cependant, l'impact de l'urbanisation sur les débits faibles, en particulier le débit de base (*baseflow*), ici défini comme la part du débit provenant de sources différées telles que les eaux souterraines, est plus complexe et moins bien compris. Cette incertitude sur la réponse du débit de base à l'urbanisation est en partie due à un manque de connaissances sur les chemins d'écoulement de l'eau. L'âge du débit de base, également appelé temps de transit, est un indicateur indirect des chemins d'écoulement souterrains à l'échelle du bassin versant, couramment utilisé en hydrologie « naturelle ». Il pourrait devenir un outil prometteur pour mieux comprendre comment l'eau se déplace dans les bassins versants péri-urbains. AQUASUBURB est un projet ANR (2026-2030) qui a pour objectif la quantification expérimentale de distributions des temps de transit du débit de base dans plusieurs rivières péri-urbaines, exutoires de quatre bassins versants couvrant un gradient d'urbanisation. Pour ce faire, des échantillons de précipitations, de débit de base, d'eau potable et de nappes seront prélevés régulièrement pendant deux ans dans quatre bassins versants contrastés suivis dans le cadre de l'OTHU (observatoire de terrain en hydrologie urbaine). Un modèle hydrologique distribué et orienté processus (J2000P) sera mis en place pour les quatre bassins versants afin de reproduire les processus de génération du débit de base. Ce résumé vise à présenter le contexte, la méthodologie et les résultats attendus du projet AQUASUBURB.

#### ABSTRACT

The impact of urbanisation and impervious areas on high flow regimes of peri-urban rivers is relatively well known : more intense and frequent peak flows. However, the impact of urbanization in low-flows, especially baseflow, defined as the share of streamflow coming from delayed sources such as groundwater, is complex and less known. This uncertainty in the response of baseflow to urbanisation is partly due to a lack of knowledge around subsurface flow paths. The age of baseflow, also named transit times, is an indicator of underground pathways at the catchment scale that is commonly used in 'natural' hydrology. Yet, it could become a promising tool to better understand how water travels underground in peri-urban catchments. AQUASUBURB is a starting project (2026-2030) that aims to estimate transit time distributions of baseflow across a gradient of urbanization. To do so, rainfall, baseflow, tap water and groundwater will be sampled weekly for two years in four contrasted catchments monitored in the OTHU program (field observatory for stormwater management) to calculate empirical transit time distributions. A process-oriented, distributed hydrological model (J2000P) will be set up for the four catchments to reproduce underground baseflow generation processes. This abstract aims to present the context, methods and expected results of the AQUASUBURB project.

#### MOTS CLÉS

Peri-urban catchment hydrology, transit times, baseflow, isotopes, hydrological modeling

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## 1 INTRODUCTION

The impact of growing urbanization and soil sealing on high flows is well known: peri-urban streams experience more frequent and intense high flows, causing flooding, erosion, and ecological degradation (Braud et al., 2013). However, the effects of urbanization on baseflow - the delayed portion of streamflow supplied by groundwater — remain complex and less understood. Baseflow can either decrease or increase with urbanization, depending on competing processes. Reduced recharge due to soil sealing, compacted soils, and network drainage can lower baseflow. Conversely, leaks from water supply systems, septic tanks, or excessive garden irrigation can raise it. This balance is influenced by the poorly understood subsurface flow paths in urban areas. Urban subsurfaces are heavily modified by buried infrastructure — pipes, cables, and utility trenches — which can act as preferential flow pathways, forming an “urban karst” (Bonneau et al., 2017). These artificial conduits alter recharge patterns and can influence pollutant transport in groundwater and baseflow, but their hydrological role remains insufficiently quantified.

A useful tool to investigate baseflow generation processes is water age or transit time (Benettin et al., 2022), which measures how long rainfall takes to leave a catchment as streamflow. Isotopic tracers ( $^{18}\text{O}$  and  $^2\text{H}$ ) are widely used to estimate these times by tracking changes in the isotopic composition of precipitation, groundwater, and streamflow. In natural catchments, mean transit times (MTT) often span several months or years. Urbanization, however, tends to accelerate water movement, resulting in shorter MTTs compared to rural or forested basins (Soulsby et al., 2014). Studies along urbanization gradients or in paired catchments consistently show faster flow paths, mainly due to the prevalence of surface and shallow subsurface routes.

Overall, the literature highlights two major insights: first, isotopic methods are powerful tools for disentangling complex hydrological processes in mixed land-use catchments; second, critical knowledge gaps persist regarding how urbanization affects groundwater flow paths and baseflow transit times. Addressing these gaps is essential for understanding how peri-urban catchments store, release, and mix waters — processes vital for sustaining river ecosystems. As climate change brings wetter winters and drier summers, knowing how urbanization alters water storage and release capacities will be key to designing resilient stormwater management strategies and restoring healthy urban streams. The project aims at answering the following research questions:

- How does urbanisation impact the age of baseflow?
- Can the integration of isotopic data in a process-oriented hydrological model improve the representation of baseflow processes?

## 2 METHODS

### 2.1 Study area

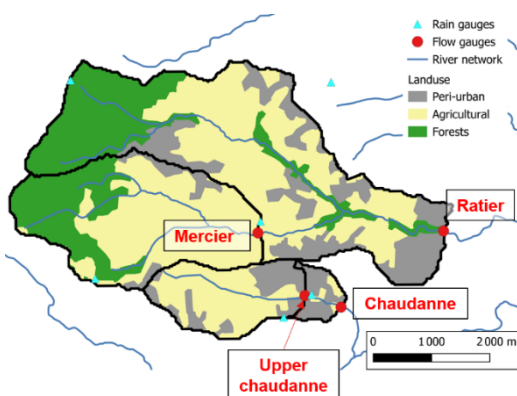


Figure 1 - Map of the studied catchments (OTHU program), in the western suburb of Lyon, France

The study will take place in two catchments in the western suburbs of Lyon, France: the Ratier and the Chaudanne catchments, respectively 19km<sup>2</sup> and 3.2km<sup>2</sup>. Underlying geology consists in metamorphic rock, soils are silty, loamy and argillaceous. In both catchments landuse is a mixture between discontinuous urban fabric (residential, peri-urbanisation), non-irrigated arable land, pastures, grasslands, meadows, cultivation areas and mixed (coniferous and broad-leaved) forests. Within these two catchments, two sub-catchments will also be studied, so in total four sub-catchments constituting a gradient of urbanization will be studied.

## 2.2 Work Package 1 - Experimental estimation of the transit times of baseflow along a gradient of urbanisation using the stable isotopes of water

### 2.2.1 Task 1.1. - defining the sampling strategy

Hydrograph separations: For 4–5 rainfall events, samples will be collected in the four streams, rainfall, one groundwater well, tap water, and a stormwater pipe. Stable isotopes of water ( $\delta^{18}\text{O}$  and  $\delta\text{D}$ ) will be analyzed to identify end-members (rainfall, groundwater, imported water) and quantify their contributions to streamflow and the timing needed for the streams to recess back to baseflow conditions after rainfall. Hourly streamflow and climate data from the BDOH database will be used to separate baseflow from streamflow (Duncan and Ladson filters, (Duncan, 2019)). Parameters will be calibrated using isotope-based hydrograph separations. Semi-empirical relationships between baseflow proportion and hydro-climatic indicators will be derived, in order to plan a sampling schedule to target baseflow-dominated conditions in Task 1.2.

### 2.2.2 Task 1.2.- field data collection

Rainfall collectors will be built following IAEA isotope hydrology guidelines. It consists of a funnel connected to a 1–2 m coiled pipe leading to a sealed bucket, minimizing isotopic fractionation by limiting evaporation before sampling. Rainfall will be considered isotopically homogeneous across each small catchment.

Rainfall, baseflow from four streams, groundwater, tap water, and stormwater (from an existing sewer station) will be sampled approximately weekly, depending on the sampling strategy defined in Task 1.1. Over 24 months, these samples will provide timeseries of the stable isotopes of water in relevant water compartments and fluxes in the studied peri-urban catchments.

### 2.2.3 Task 1.3 - transit time distributions fitting

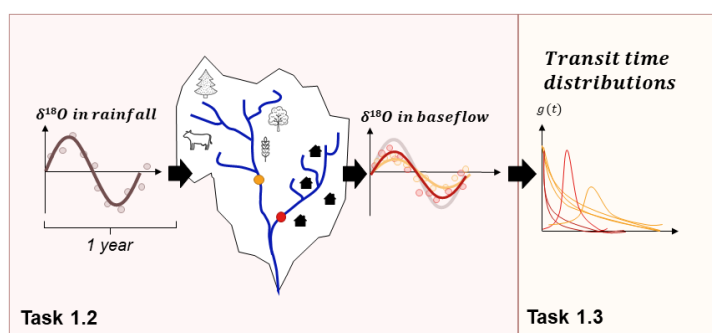


Figure 2 - Conceptual description of Tasks 1.2 and 1.3.

Using data from Task 1.2, experimental baseflow transit times will be estimated by fitting modeled tracer concentrations to observations (deconvolution of the tracer input (precipitation) and a transit time distribution). Three common time-invariant transfer functions will be tested: (1) the exponential model, suitable for well-mixed catchments; (2) the gamma model, and (3) the two-parallel linear reservoir (TPLR) model, representing fast and slow flow components. Model parameters will be optimized using Monte Carlo simulations to maximize the Kling–Gupta Efficiency (KGE) between modeled and observed  $\delta^{18}\text{O}$ . The young water

fraction—the share of baseflow younger than 2–3 months—will also be estimated from the seasonal amplitude ratio of  $\delta^{18}\text{O}$  in precipitation and baseflow.

## 2.3 Work Package 2 - Integrating the age of water in a process-based hydrological model and improvement of the representation of baseflow processes

### 2.3.1 Task 2.1- model calibration with flow and isotopic data

This task aims to develop and calibrate J2000P models for the Ratier and Chaudanne catchments using flow and isotope data. J2000P is a peri-urban adaptation of the physically based, distributed, and open-source hydrological model J2000 (Branger et al., 2012). It runs at an hourly timestep and accounts for sewer networks and sewer overflow devices (SOD). The model operates on irregular Hydrological Response Units (HRUs)—areas with homogeneous soil, geology, and land use—where hydrological processes are simulated. These include canopy interception, surface runoff (RD1), soil infiltration, and storage in medium (MPS) and large pores (LPS), percolation from the soil that feeds interflow (RD2) and groundwater stores (RG1, RG2), drained as linear reservoirs. At each timestep, all fluxes are routed downslope or into the hydrographic network using a kinematic wave approach. The Ratier model will be built on an existing one, while the Chaudanne model will be created using available DEM, geological, soil, and land-use maps.

Simulations will run from 1997 to the present, allowing to extract simulated flow at the catchment outlets, for calibration. Calibration will target parameters controlling baseflow: the OPTAS assistant in J2000 will be used, maximizing  $KGE(vQ)$  and  $KGE(\log_{10}(Q))$  for low-flow performance. Two parameter sets will be derived: one based solely on streamflow, and another constrained by isotope data using a newly developed module for simulating stable isotope transport in urban baseflow (Watson et al., 2024).

### 2.3.2 Task 2.2. – improved conceptualization of urban subsurface flow paths.

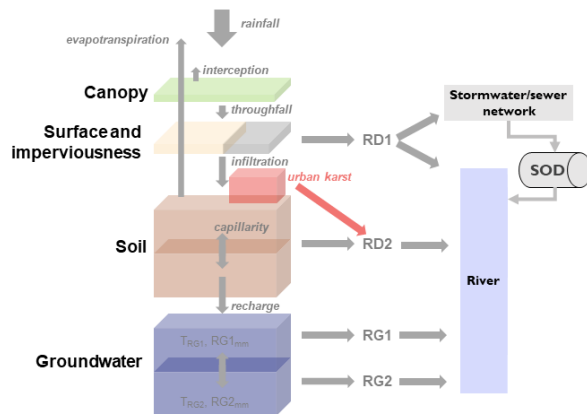


Figure 3 - Conceptual view of the J2000 model with the new 'urban karst' module to be implemented (red box) Adapted from Watson et al. (2024) and Labbas (2013)

This task aims to develop an “urban karst” module in J2000P to better represent subsurface transport processes in urban areas. In Task 2.1, it is hypothesized that the integration of isotopic data in the model will result in improved calibration, yet without changing processes representation. Here, the new module will explicitly simulate urban subsurface exchanges to test whether this conceptual improvement enhances baseflow prediction.

Based on findings from WP1, the module will represent: (1) groundwater–stormwater interactions, (2) leakage from drinking water networks, and (3) accelerated subsurface transport in gravel trenches, modeled as a rapid linear reservoir.

## 3 EXPECTED RESULTS AND CONCLUSIONS

The AQUASUBURB project will thus provide an innovative dataset (isotopic composition of different end-members of the peri-urban water cycle). It will shed light on the age of baseflow, allowing a better understanding of transport processes in peri-urban catchments. The project will also provide two hydrological models of peri-urban catchments, integrating isotopic composition of water fluxes and an improved conceptualization and understanding of baseflow processes.

## BIBLIOGRAPHIE

- Benettin, P., Rodriguez, N.B., Sprenger, M., Kim, M., Klaus, J., Harman, C.J., Van Der Velde, Y., Hrachowitz, M., Botter, G., McGuire, K.J., Kirchner, J.W., Rinaldo, A., McDonnell, J.J., 2022. Transit Time Estimation in Catchments: Recent Developments and Future Directions. *Water Resour. Res.* 58, e2022WR033096. <https://doi.org/10.1029/2022WR033096>
- Bonneau, J., Fletcher, T.D., Costelloe, J.F., Burns, M.J., 2017. Stormwater infiltration and the ‘urban karst’ – A review. *J. Hydrol.* 552, 141–150. <https://doi.org/10.1016/j.jhydrol.2017.06.043>
- Branger, F., Kermadi, S., Krause, P., Labbas, M., Jacqueminet, C., 2012. Investigating the impact of two decades of urbanization on the water balance of the Yzeron peri-urban catchment, France. Presented at the 6th International Congress on Environmental Modelling and Software, Leipzig, Germany.
- Braud, I., Breil, P., Thollet, F., Lagouy, M., Branger, F., Jacqueminet, C., Kermadi, S., Michel, K., 2013. Evidence of the impact of urbanization on the hydrological regime of a medium-sized periurban catchment in France. *J. Hydrol.* 485, 5–23. <https://doi.org/10.1016/j.jhydrol.2012.04.049>
- Duncan, H.P., 2019. Baseflow separation – A practical approach. *J. Hydrol.* 575, 308–313. <https://doi.org/10.1016/j.jhydrol.2019.05.040>
- Soulsby, C., Birkel, C., Tetzlaff, D., 2014. Assessing urbanization impacts on catchment transit times. *Geophys. Res. Lett.* 41, 442–448. <https://doi.org/10.1002/2013GL058716>
- Watson, A., Kralisch, S., Miller, J., Vystavna, Y., Gokool, S., Künne, A., Helmschrot, J., Arciniega-Esparza, S., Sanchez-Murillo, R., Birkel, C., 2024. Advancing isotope-enabled hydrological modelling for ungauged calibration of data-scarce humid tropical catchments. *Hydrol. Process.* 38, e15065. <https://doi.org/10.1002/hyp.15065>