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# Runoff volume reduction performance of a pervious detention basin located in a shallow groundwater and low-permeability soil context

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## Highlights

- Significant runoff volume-reduction despite a low permeability soil and a shallow groundwater (GW).
- Loss-rates estimated at hourly time-steps within an uncertainty analysis framework.
- High variability of loss-rates with a possible influence of GW and permeability contrasts in the basin.

## Introduction

Managing stormwater in shallow groundwater (GW) and low-permeability soil contexts often proves to be challenging due to limited infiltration possibilities (Zhang and Chui, 2019). Yet, current research suggests that pervious green stormwater infrastructure (GSI) still provide opportunities for runoff volume reduction under such conditions, albeit at the price of a degraded functioning (Pophillat et al., 2022). Objectivizing and understanding the hydrological performance of pervious GSI in shallow GW and low-permeability context is crucial to facilitate their implementation where appropriate. Current knowledge however remains limited by the small number of field studies in such unfavourable settings (Zhang and Chui, 2019).

Indeed, GSI monitoring is an essential step to identify dominant processes and inform further numerical, model-based, analysis that extend to other conditions than those observed on-site. This step is however often challenged by significant uncertainties, that, despite their potential impact on the conclusions drawn about the functioning of studied system, are still rarely accounted for.

This abstract presents preliminary results from the long-term monitoring of a pervious landscaped basin, located in an area where soil and hydrogeology conditions are not conducive to infiltration. The analysis focusses on the long-term volume reduction efficiency provided by the basin and the variability of infiltration losses in relation with other variables including surrounding GW levels. The work is conducted within a measurement uncertainty propagation framework, so as to assess the robustness of current results and highlight the benefits of such approach for GSI monitoring studies.

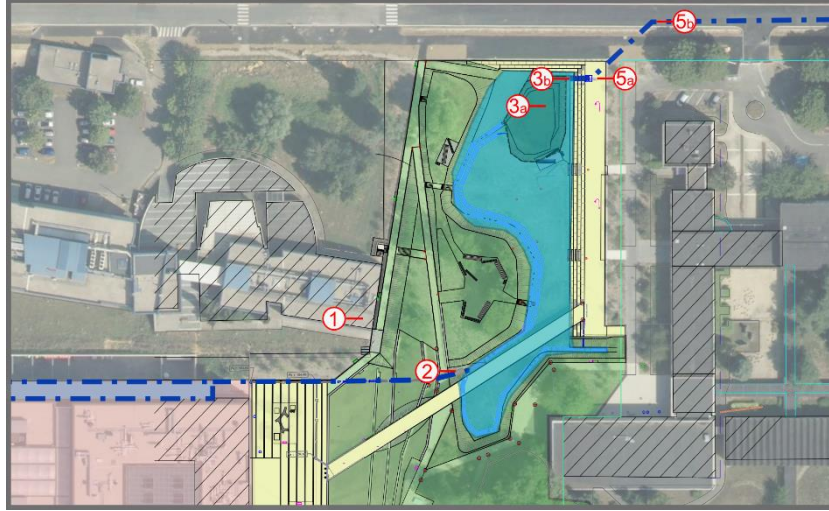
## Methodology

### Site description

The site is located on the Paris-Saclay cluster, 25km *south-west* of Paris, a large development project extending over a silt-clay plateau holding a shallow, almost outcropping, aquifer. The facility consists of a 2.300 m<sup>2</sup> landscaped basin that collects discharge from a 20.000 m<sup>2</sup> building as well as the runoff from adjacent impervious and pervious surfaces (respectively 2.000 and 10.500 m<sup>2</sup>) (see Figure 1). In the case of the building, discharge occurs as a pumping from an underground storage basin where both roof runoff and drainage water from building foundations (i.e., to keep basement dry) are directed. This configuration thus results in a partial decoupling between inflow to the basin and rainfall.

The basin was originally designed to provide storage for the 50-yr storm, under the assumption of negligible infiltration capacity. Water is thus expected to be discharged at a controlled-rate through an about 4-cm diameter orifice allowing to maintain outflow-rate below 2.3 l/s. The elevation of the orifice is approximately 153.5 m MSL, i.e., about 1.7 m below nearby ground level. The basin also incorporates a small permanent

storage volume, forming a 200 m<sup>2</sup> reedbed, near the outlet and reaching about 152.7 m MSL at its lowest point. The infiltration capacity of the system is not precisely known. Surface measurement campaigns conducted with different methods revealed a strong heterogeneity of soil conditions at the bottom of the system and allow to situate soil saturated hydraulic conductivity between less than 10<sup>-7</sup> m.s<sup>-1</sup> and 10<sup>-4</sup> m.s<sup>-1</sup>. Infiltration tests mentioned in pre-construction surveys show significantly lower values, with 2×10<sup>-9</sup> m.s<sup>-1</sup> to 5×10<sup>-7</sup> m.s<sup>-1</sup> and 2×10<sup>-7</sup> m.s<sup>-1</sup> to 10<sup>-5</sup> m.s<sup>-1</sup> for boreholes and surface testings respectively.



**Figure 1. Configuration of studied basin and monitoring setup. Blue area: storage area. Green-area: contributing pervious surfaces. Yellow area: contributing impervious surfaces. Red area: building from which most of the rainfall originates. Red circles: sensor location with 1: rain gauge; 2: inflow; 3a and 3b: water-level**

The basin has been monitored since 2021 (Figure 1). A v-notch weir system is adopted to measure discharge from the building ( $Q_{in,b}$ , 1-min timestep). Water-level is measured within and right above the reedbed (5-min time step). Outflow ( $Q_{out}$ , 5-min time step) measurement involves a v-notch weir for low-flows and an orifice law for high flows. In all cases, measurement rely on independent water-level dataloggers (In-situ Level Troll 500 for behind weirs and the orifice; Solinst Levellogger 5 for water-level near the reedbed). Rainfall is monitored close to the basin with a 0.1 mm tipping bucket rain gauge. Finally, a piezometer installed about 50 m south from the basin allows to monitor GW levels ( $Z_{GW}$ , hourly timestep).

### Data analysis

A Monte-Carlo approach (Bertrand-Krajewski et al., 2021) is adopted for the propagation of uncertainties, considering various error sources (sensor, weir or orifice characteristics, elevation-surface-volume relationship, contributing surface for  $Q_{in,adj}$ ...) based on current knowledge. Under this approach, random samples can be generated for the different timeseries involved in water balance calculations. As a preliminary work, the propagation here only relies on 100 samples for the different variables.

The water balance between two dates  $t_{start}$  and  $t_{end}$  is assessed from the following equation:

$$S(t_{end}) = S(t_{start}) + \int_{t_{start}}^{t_{end}} (R + Q_{in,adj} + Q_{in,b} - Q_{out} - Q_{loss}). dt \quad (1)$$

Where:  $R$  is direct rainfall ([L<sup>3</sup>.T<sup>-1</sup>]);  $Q_{in,adj}$ : runoff from adjacent surfaces (estimated from rainfall) ([L<sup>3</sup>.T<sup>-1</sup>]);  $S(t)$ : surface storage at a given date ([L<sup>3</sup>]);  $Q_{loss}$ : loss-rate ([L<sup>3</sup>.T<sup>-1</sup>]).

The cumulative water balance over the monitoring period (June 2021 to November 2023) is first estimated based on available measurements. A more detailed analysis of  $Q_{loss}$  is then performed based on the same equation. An area normalization is introduced to express this term as m.s<sup>-1</sup>, considering the wetted area estimated from surface water-levels. The analysis focuses on periods with limited inflow (less than 1 m<sup>3</sup>/h). A 12-h moving average smoothing is additionally applied to the different water-balance variables after a 1h-resampling to reduce noise in the estimation of  $Q_{loss}$ . Corresponding values are later denoted as  $q_{loss,h}$ .

## Results and discussion

### Overall functioning and water balance

Over the studied period, the system rarely completely empties and the reedbed remains submerged for approximately 90% of the time. During these periods, wetted area rarely exceeds 300 m<sup>2</sup> indicating that storage primarily occurs nearby the reedbed, with limited elevation (less than 10 cm above the upper limit of the reedbed), and only temporarily extends to the rest of the garden. This relatively low elevation is however often associated with non-negligible discharge, with 36% of the studied periods with outflow rates above 0.01 l.s<sup>-1</sup>. Regarding underground conditions, GW levels downstream the basin range between 153 m and 155 m MSL and thus often exceeds the elevation of the outflow orifice.

The cumulative water balance is shown in figure 2. Over the studied period, the garden received between 24.000 and 27.000 m<sup>3</sup> of water, predominantly originating from the buried basin (~80% of inflow being associated with  $Q_{in,b}$ ). This volume mainly consists of runoff from the roof (~83%), but also includes a non-negligible proportion of underground water. Despite the uncertainties in the estimation of the different terms of the water balance, the overall loss can be quite satisfactorily estimated. The later here represents a significant fraction of incoming volume (43 to 55%), suggesting that despite the unfavourable soil conditions and hydraulic loading (more than 22.000 m<sup>2</sup> of impervious areas for a 2.300 m<sup>2</sup> infiltration area), the volume reduction benefits of the system remain significant. Based on potential evapotranspiration (ET) estimates from nearby weather station, it can be concluded that, even if surface evaporation was occurring at potential rate from wetted area, the latter should not represent more than 3% of the observed volume reduction. Runoff reduction is thus essentially associated with infiltration.

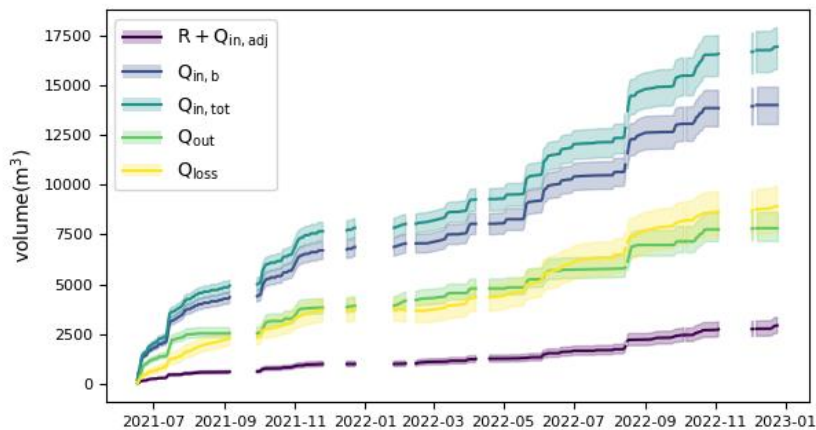


Figure 2. Cumulative water balance over studied period. Shaded area: min-max coverage. Solid line: median value.

### Variability of loss-rate estimates

The distribution of hourly loss-rate estimates ( $q_{loss,h}$ ) is presented in figure 3.

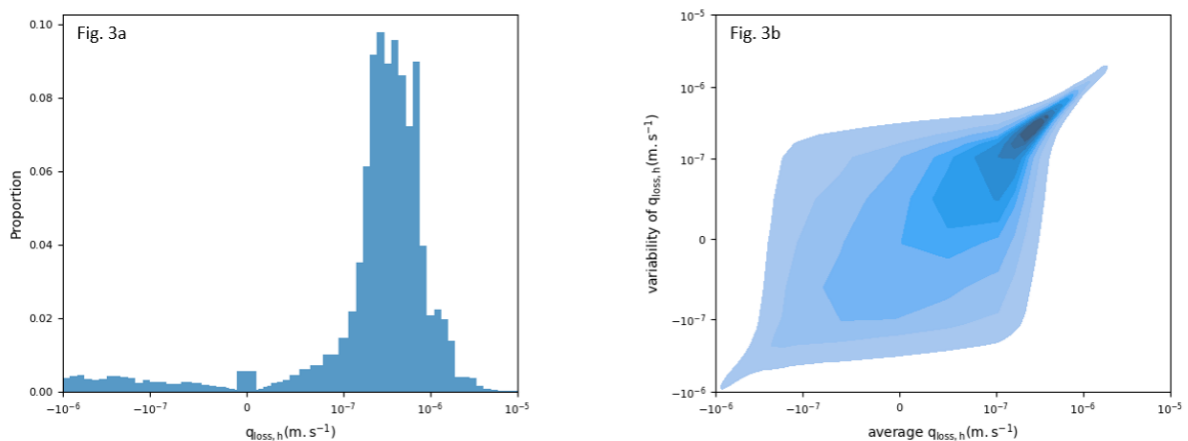
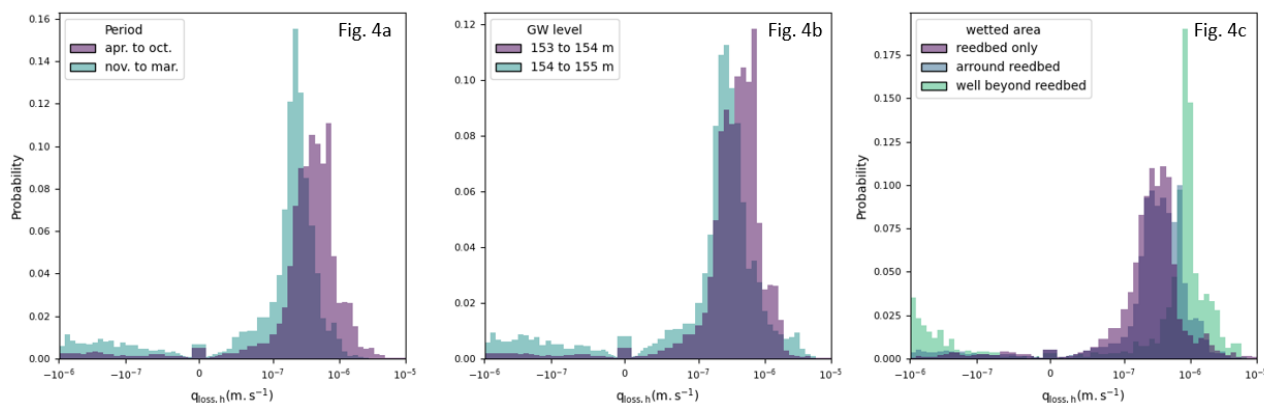


Figure 3. Distribution of  $q_{loss,h}$ . 3a: Distribution over the studied period and across the different Monte-Carlo samples. 3b: variability resulting from uncertainty propagation as a function of mean  $q_{loss,h}$  (shaded area represents the number of counts).

For the 5<sup>th</sup> to 95<sup>th</sup> percentiles of the distribution,  $q_{\text{loss,h}}$  ranges between  $-2 \times 10^{-7} \text{ m.s}^{-1}$  and  $1 \times 10^{-6} \text{ m.s}^{-1}$  (fig. 3a). A large proportion the values concentrate between  $2 \times 10^{-7}$  and  $7 \times 10^{-7} \text{ m.s}^{-1}$ , which is in the lower range of measured infiltrations capacities. The significance of the negative values yet remains unclear. Sensitivity tests on smoothing windows and inspection of the uncertainty as a function of mean estimated loss-rate (fig. 3b) however indicate that these negative losses probably do not result from noise and are not subject to higher uncertainties than positive values. While  $q_{\text{loss,h}} < 0$  could reflect soil water intrusion, caution is required as this situation might also be associated with water-balance errors that are not captured through this analysis. The variability of loss-rate shows a significant seasonal trend with marked differences between wet and dry periods (Fig. 4a), that could directly result from the seasonal variability of both ET and  $Z_{\text{GW}}$ . Separating the contribution of ET reduction and GW level increase is not however straightforward as the phenomena are concomitant. The co-variability of GW levels on  $q_{\text{loss,h}}$  is shown in figure 4b. Higher GW levels are not only associated with lower loss-rates ( $2.5 \times 10^{-7}$  vs.  $4 \times 10^{-7} \text{ m.s}^{-1}$  for median values), but also with a larger proportion of negative flows, again pointing towards the hypothesis of GW intrusion. Finally, a significant impact of wetted area is also observed, with higher loss-rates when the latter extends way beyond the reedbed (median value around  $10^{-6} \text{ m.s}^{-1}$ ) which could reflect differences in soil permeability within the basin. Surprisingly,  $q_{\text{loss,h}} < 0$  also occurs more frequently when wetted area extends far beyond the reedbed, which suggests the phenomena results from the combination of wet (and high GW level) periods with significant solicitation of the basin.



**Figure 4.** Distribution of loss-rates  $q_{\text{loss,h}}$  depending on different factors. 4a: depending on the period of the year. 4b: depending on GW levels. 4c: depending on wetted area (classes: 0 to 200 m<sup>2</sup>, 200 to 400 m<sup>2</sup> and more than 400 m<sup>2</sup>).

## Conclusions and future work

Hydrologic losses from a pervious retention basin located in a low permeability and shallow GW context were analysed. Despite high hydraulic loading and unfavourable soil and hydrogeology conditions, the long-term volume reduction of the basin was found to be significant and essentially associated with infiltration. A strong temporal variability of loss-rates was evidenced, with i) a potential influence of GW levels and ii) increased soil infiltration capacity on less frequently wetted zones of the basin. The experiment is still ongoing. Future work will include improved characterization of the different uncertainty sources to consolidate the analysis. A more detailed examination of the determinant of loss-rates should also be conducted with for instance an assessment of the impact of soil moisture conditions and additional soil infiltration tests.

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