The role of natural ponds in controlling the urban runoff regime

Le rôle des étangs dans le contrôle du ruissellement urbain

Guido Petrucci, Kevin De Bondt, Philippe Claeys

Analytical, environmental and geo-chemistry (AMGC), Vrije Universiteit Brussel (VUB), Pleinlaan 2, 1050 Brussels, Belgium
guido.petrucci@vub.ac.be

RÉSUMÉ

L'urbanisation, au-delà de l'augmentation des surfaces imperméables, entraine souvent une réduction des étangs et des zones humides naturellement présents le long des cours d'eau. Ce processus, peu étudié, contribue à déterminer les modifications du régime hydrologique des bassins versants en réduisant la capacité de stockage et de rétention du ruissellement. Sur la base de données issues de sept points de mesures dans un bassin versant (50 km²) de la Région de Bruxelles, cette communication présente une comparaison entre le régime hydrologique de zones boisées et urbaines. Ensuite, par la simulation d'une série de scénarios représentant la croissance de l'imperméabilisation et la disparition des étangs dans un sous-bassin versant actuellement boisé, le rôle respectif de ces deux processus associés à l'urbanisation est évalué. Le résultat principal est que, si les deux processus ont des effets comparables, seule leur combinaison permet d'expliquer le passage du régime naturel au régime urbain observé.

ABSTRACT

Urbanization, beside an increase in impervious cover, is often associated with a reduction of natural ponds and wetlands along streams. This process is poorly studied in urban hydrology literature, but contributes to modify the hydrological regime of urbanizing catchments by reducing the storage capacity available to retain runoff. This communication presents a research using data from seven gauging stations in a catchment (50 km²) of the Brussels Region. First, these data are used to compare the hydrological regime of urbanized and forested catchments. Then, a set of scenarios are simulated over a forested subcatchment. Scenarios include an increase in the impervious cover of the catchment and the removal of existing ponds, in order to test the respective role of each of these processes. The main result is that, even if the two processes have similar effects, only the combination of both allows explaining the shift from the observed natural regime to the urban one.

KEYWORDS

Flow-duration curves, Hydrologic regime, Ponds, Urbanization, Urban runoff

1 INTRODUCTION

The impact of urbanization on runoff regime is extensively studied since several decades (Leopold, 1968; Fletcher et al., 2013). Urbanization affects both runoff peaks, responsible of flooding, and the whole regime of low flows, with consequences on the stability and ecology of downstream water bodies (Walsh et al., 2005). Several processes associated with urbanization modify the runoff regime. Among them, the most studied and known is the sealing of the natural landscape with impervious surfaces (Jacobson, 2011), reducing infiltration and increasing surface runoff. Another aspect sometimes mentioned is the increased smoothness of urban surfaces and artificial drainage, accelerating runoff (Salvadore et al., 2015). A third process, poorly considered by urban hydrology literature, is the removal of natural ponds and wetlands (Fig. 1). Natural ponds play a role of "buffer" of the runoff regime, thanks to their storage capacity and the exchanges with groundwater. These ponds are often filled and covered during the urbanization processes, reducing this buffer effect. Artificial ponds and reservoirs are considered as a flood-reduction measure, but their functioning is not always the same as natural ones: they are often built on a by-pass of the normal water flow in order to fill only during heavy storms and they can be isolated from groundwater.

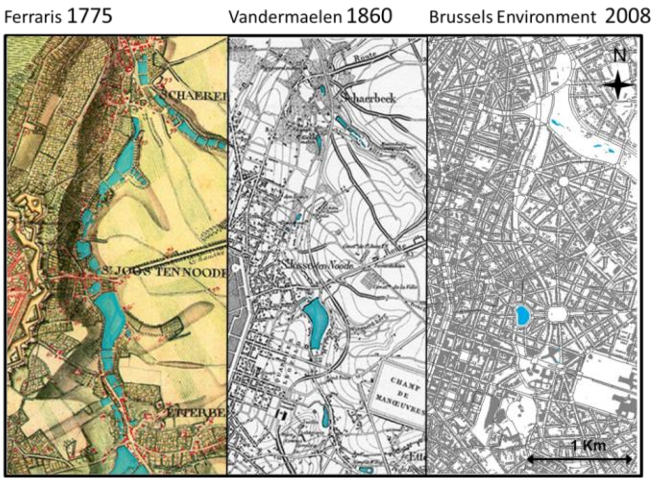

Figure 1 - Example of ponds removal with urbanization in Brussels

This research studies the role of natural ponds on the runoff regime of urban catchments. The case-study used, the Woluwe catchment, is a part of the Brussels Capital Region, including several gauged subcatchments, both natural and urbanized. The methodology consists in two steps. The first, based on data-analysis, aims at the identification of the runoff regime of urban and natural subcatchments. The second, based on modelling and scenario analysis, is used to distinguish the role of imperviousness and natural pond filling in modifying the runoff regime of the natural catchments.

2 METHODOLOGY

2.1 Case study: the Woluwe catchment

The Woluwe is a small river flowing in the East of the Brussel Capital Region (Fig. 2). Its catchment covers roughly 50 km²: 30 km² of urban areas (average imperviousness of about 20%) and the remaining 20 km² covered by a forest. The drainage system is constituted by the river, collecting water from the forested area and from some parks in the valley, and by a combined sewer draining water from the urban parts of the catchment. About 40 combined sewer overflows (CSO) link the two systems. The natural drainage system includes several large ponds (although less than in the pristine state), both in the valley bottom and in the upstream subcatchments. The gauging network includes two stations on the river, two on its tributaries and three on the sewer. Discharge data used, available on the Flowbru website, covers different periods ranging between 2 and 12 years.

2.2 Data analysis and modelling

Data from the seven gauging stations are used to produce flow-duration curves (FDC, Vogel and Fennessey, 1994; Petrucci et al., 2014). For gauges where only 2 years of data are available, the FDC is computed over the complete duration. For the others, a median annual FDC was computed.

To assess the respective role of imperviousness and pond filling, a detailed model of one of the forested subcatchments was realized (RKB). The model used is SWMM, calibrated over one year of 5' time-step data using a genetic algorithm (Petrucci and Bonhomme, 2014). Once the model calibrated on the actual conditions (forested, with ponds), three scenarios were simulated and compared to the case of WMB, a subcatchment with similar characteristics except for urbanization: A) increase in imperviousness of 30% (value of the WMB catchment); B) filling of the existing ponds; C) combination of 30% imperviousness and filling of the ponds.

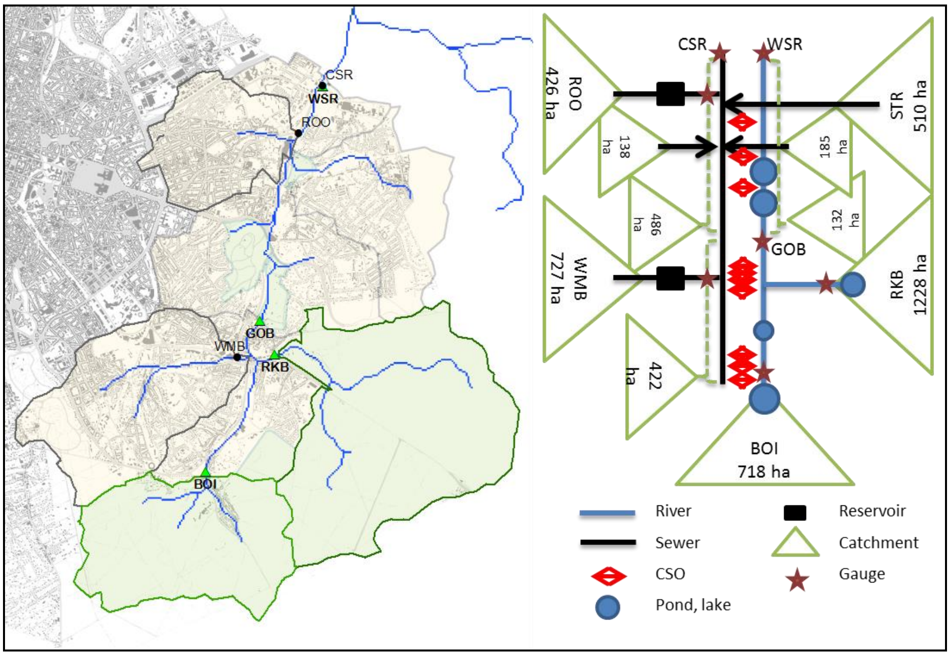

Figure 2 – Map and scheme of the Woluwe catchment in the Brussels region. In the map: grey lines are the limits of the urban gauged subcatchments; black dots are the gauging stations. Green lines are the limits of the natural gauged subcatchments, with gauging stations marked by green triangles. Labels are the codes of the gauging stations, as in the scheme and in Fig. 3.

3 RESULTS AND KEY FINDINGS

Results of data analysis for the seven stations are synthesized in Fig. 3. The distinction between the natural and urban catchments in two groups of curves is evident. Natural catchments have extremely stable discharges, always ranging between 0.02 and 0.3 L/s/ha (note: BOI station is downstream of a sewer overflow, so its relatively high discharges at low frequencies can be due to interactions with the sewer). Conversely, urban catchments discharge ranges between 0.03 and 8 L/s/ha, spanning over two orders of magnitude. The highest variability occurs during wet periods (frequency < 5%), while in dry periods low flows are represented by waste water.

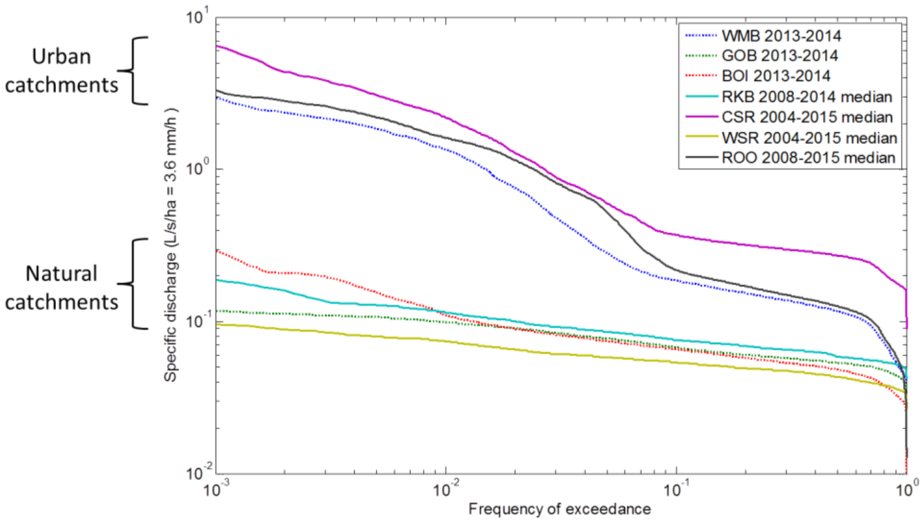

Figure 3 – Flow duration curves for the seven gauging stations

Results of scenario simulation are presented in Fig. 4. Two “extreme” references are provided: the green FDC, extremely flat over the year, represents the natural conditions with forest and ponds; the black FDC represents, conversely, data from the WMB catchment, close and geographically similar to RKB, but urbanized (30% imperviousness, no ponds but a stormwater reservoir for flood prevention).

In terms of low flows, the three scenarios present a strong reduction in discharge, which in the real catchment is compensated by the presence of waste water. With 30% imperviousness, discharge at the outlet is present for 70% of the year (100% in the pristine state), without ponds for 55%; the combined effect is that water flows at the outlet only 16% of the time.

In terms of high flows the filling of ponds has a smaller effect than the increase of imperviousness: for a 1 ‰ frequency, discharge increases from 0.15 to 0.6 L/s/ha without ponds and to 1.1 L/s/ha for 30% imperviousness. But the interesting result is that the combination of the two modifications produces a curve for wet periods that is extremely close to that of the real urban catchment (1 ‰ discharge is 4 L/s/ha). Apparently, neither the ponds nor imperviousness can, alone, explain the runoff regime of the urban catchment, but the two together do it extremely well.

Moreover, considering both low and high flows, the combined effect of ponds removal and imperviousness is larger than the sum of the two effects considered separately. The reduction of the buffer effects of ponds enhances the impact of increased urbanization, and vice versa.

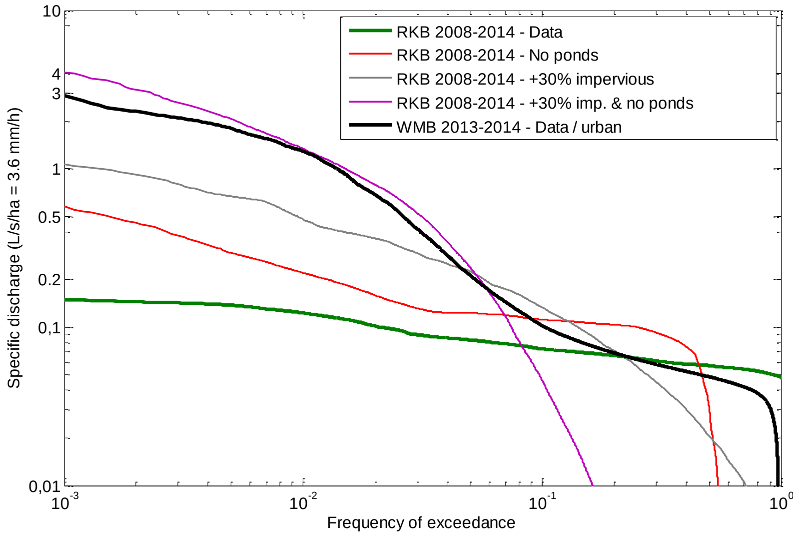

Figure 4 – Flow duration curves for the urbanization scenarios of the RKB catchment

LIST OF REFERENCES

Fletcher T. D., Andrieu H., Hamel P. (2013). Understanding, management and modelling of urban hydrology and its consequences for receiving waters: A state of the art. Advances in Water Resources, Volume 51, 261-279.

Jacobson C.R. (2011). Identification and quantification of the hydrological impacts of imperviousness in urban catchments: A review. Journal of Environmental Management 92(6), 1438-1448.

Leopold L. B. (1968). Hydrology for urban land planning: A guidebook on the hydrologic effects of urban land use. US Government Printing Office.

Petrucci G., Bonhomme C. (2014). The dilemma of spatial representation for urban hydrology semi-distributed modelling: trade-offs among complexity, calibration and geographical data. Journal of Hydrology 517, p. 997-1007.

Petrucci G., Rodriguez F., Deroubaix J.-F., Tassin B. (2014). Linking the management of urban watersheds with the impacts on the receiving water bodies: the use of flow duration curves. Water Science and Technology, 70.1, 127-135.

Salvadore E., Bronders J., Batelaan O. (2015). Hydrological modelling of urbanized catchments: A review and future directions. Journal of Hydrology, 529, 62-81.

Vogel R. M. and Fennessey N. M. 1994 Flow-Duration Curves. I: new interpretation and confidence intervals. Journal of the American Water Resources Association 120(4), 485-504.

Walsh C. J., Roy A. H., Feminella J. W., et al. (2005). The urban stream syndrome: current knowledge and the search for a cure. Journal of the North American Benthological Society, 24(3), 706-723.