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Influence of retention basins on the outflows of the upper part of Bièvre catchment and interest of radar measurements for its hydrological modelling

Influence des bassins de rétention sur les débits du bassin versant amont de la Bièvre et intérêt de la mesure radar pour sa modélisation hydrologique

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RÉSUMÉ

Les bassins de rétention figurent parmi les moyens permettant de réduire les débits d'eaux pluviales urbaines. Par ailleurs la mesure en temps réel de la pluie par radar météorologique est susceptible d'aider à la gestion de ces bassins de rétention. L'étude réalisée a pour but d'évaluer le niveau d'influence des bassins de rétention sur les écoulements et d'étudier l'intérêt de la mesure radar pour l'estimation des débits au niveau du bassin versant amont de la Bièvre, bassin versant de 120 km² géré par le SIAVB. Pour cela un modèle hydrologique distribué a été utilisé selon différents scénarios au cours de 6 événements pluvieux. Cette modélisation a montré l'efficacité des bassins de rétention quant à la diminution des débits. Par ailleurs, elle a mis en évidence que, pour les 6 événements étudiés, les données radar spatialisées par rapport aux données des 6 pluviomètres du SIAVB ne permettaient pas d'améliorer la gestion des bassins de rétention de ce bassin versant. Une explication avancée est que les 6 pluviomètres recouvrent correctement le bassin versant, au moins pour les pluies étudiées.

ABSTRACT

Retention basins are commonly used to reduce peak urban stormwater flows. In addition, real time measurement of rainfall thanks to a weather radar may help the management of those retention basins. This paper deals with the evaluation of the influence of retention basins on the flows of the upper part of Bièvre catchment (120 square kilometres wide, monitored by the SIAVB) and the use of radar measurements for the hydrological modelling of the catchment. In this framework, a distributed hydrological model has been used to evaluate different scenarios during 6 different rain events. This modelling has shown the efficiency of the retention basins to reduce flows. Moreover, it has highlighted that for the 6 studied events and compared to the 6 rain gauge data of the SIAVB, spatialized radar data do not enable an improvement of the management of the retention basins of this catchment. A proposed explanation is that the 6 rain gauges are at an appropriate resolution for effectively modelling the catchment, at least for the studied events.

KEYWORDS

Bièvre catchment, Distributed hydrological modelling, Efficiency of retention basins, Interest of radar images

1 INTRODUCTION

Population density and urban extension are factors that make cities vulnerable to floods and pollution. In such a context, rainwater managements evolve rapidly. Their main goal is to develop a management of the water cycle in urban area not only able to limit flows in the direction of the natural environment but also to comply with the demands of sustainable development. Retention basins are one of the preferential tools to control flows and the improvement of the management of those structures is a strong operational and scientific issue. Radar data, characterized by high space-time resolution (order of km^2 and few minutes), can contribute to a more effective management in real time of those retention basins. However if the qualitative use of weather radar by managers of urban sewer networks or hydrologic services, is now well established, more quantitative applications of the radar are still not well developed. For a major part, this observation can be explained by the difficulties to transform radar images into rainfall intensity images (Einfalt *et al.*, 2004). The research effort has therefore focused on the understanding and the correction of the errors peculiar to radar measurements. Significant progresses have been made and in particular have allowed the deployment of the new quantitative precipitation estimation product developed by Meteo France within the French operational radar network (Tabary, 2007).

Our study deals with the hydrological modelling of the upper part of the Bièvre catchment (south-west of Paris). This 120 km^2 catchment is monitored by the SIAVB¹. In order to reduce flood hazard, the SIAVB has built numerous rainfall water retention basins. Besides, this area has been particularly well equipped: 6 rain gauges and numerous flow stations correlated to the rainfall intensity images of the weather radar of Trappes. In this context, our goal was to assess the efficiency of the retention basins with regard to decreasing flows and also to study the possible contribution of radar images to the hydrological modelling of this catchment and consequently to the management of the retention basins.

2 STUDY AREA

At 15 kilometres south-west of Paris, the Bièvre River flows about thirty kilometres from its spring to its outlet in the Seine River in Paris. The Bièvre catchment can be divided into two main parts: an upstream part, where the river flows out in the open and a downstream part, from Antony up to its outlet, where the river is canalized and buried.

The study area represents a region of approximately 120 km^2 , corresponding to the upper part of the catchment (from the commune of Buc to the commune of Wissous) and is monitored by the SIAVB. This area is drained by 18 km of river and tributaries. The land use is very heterogeneous with notably very urbanized areas (11% of the territory, *Figure 1*). The time of concentration from the upper part varies from 1 to 4 hours and those relatively short values engender rapid flooding. In reaction to the significant damage caused by the storm of July 1982 (110 mm in 3 hours), the SIAVB has developed an investment program. Its goal is to regulate the discharges engendered by rainfalls characterized by a return period of 20 years (by laminating peak flows thanks to an increase of the water retention capacity of the bottom of Bièvre valley). So, the SIAVB disposes of a very complete hydraulic infrastructure with several retention basins of a total capacity of 642000 m^3 . Those retention basins are monitored by an automated system of teleprocessing which can be local or optimized. In the case of local management, each basin is regulated according to its critical downstream section, whereas for an optimized management the regulation is global. For an optimum regulation of the river, each basin is equipped of level measure sensors. Thanks to those sensors, the discharges at the entrance and exit of each retention basin are known. To reinforce this monitoring, many flow stations have been placed in the Bièvre River to obtain a real time global view of the valley. 6 rain gauges have also been placed at strategic points to optimize the analysis of rainfall events which affect the valley (*Figure 1*). Afterwards the data are sent to the teleprocessing sets located inside the offices of the SIAVB. So, synthesis maps of the entire valley are available to control the river and they enable to decide the actions of regulation to undertake.

¹ SIAVB: Syndicat Intercommunal pour l'Assainissement de la Vallée de la Bièvre

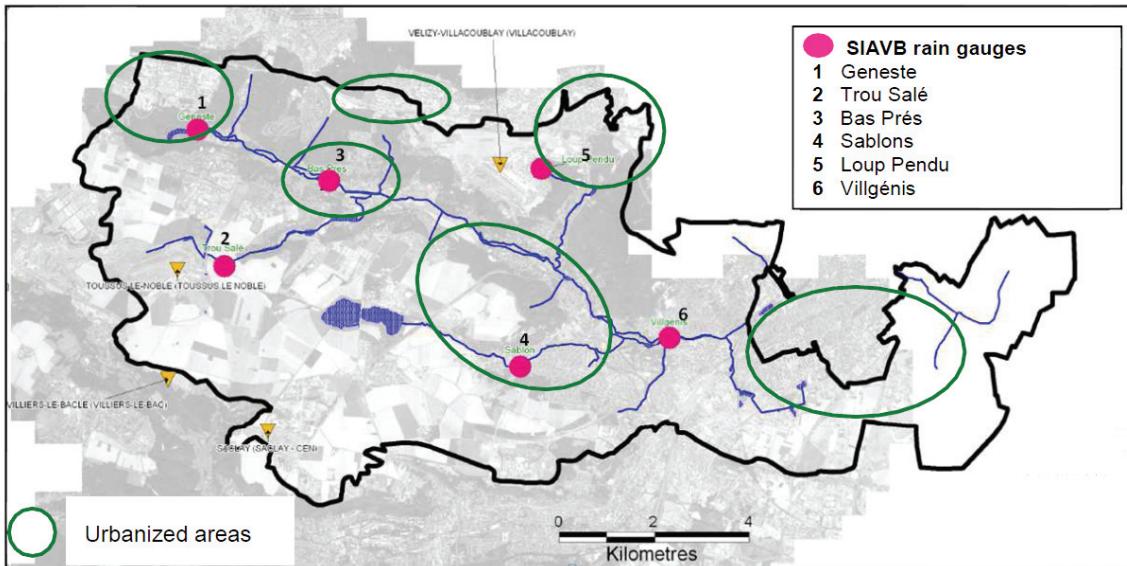


Figure 1: Map of the upper part of the Bièvre catchment showing the location of the urbanized areas and the location of the 6 rain gauges of the SIAVB.

3 DATA AND MODEL USED

3.1 Rain gauge data

The rain gauge data are provided by the 6 tipping bucket rain gauges of the SIAVB (*Figure 1*), located from 8 to 19 km around the weather radar of Trappes.

3.2 Radar data

The Radar data are measured by the C-band weather radar of Trappes located 30 km south-west of Paris. These data, of $1 \times 1 \text{ km}^2$ of spatial resolution, have been processed by the new processing algorithm developed by Meteo France. This algorithm includes a series of modules aimed at the correction of ground clutter, partial beam blocking, Vertical Profile of Reflectivity effects and advection (Tabary, 2007; Tabary *et al.*, 2007). The Marshall-Palmer Z-R relationship is used to convert reflectivity into rain rate (expressed as mm per 5 min). Those 5 min rain accumulations are also adjusted. The adjustment method consists in computing an adjustment factor every hour from rain gauge and radar data (this factor being applied to the entire image during the next hour). By comparing data from 87 rain gauges to the ones measured by the weather radar of Trappes during 50 rain events, Emmanuel *et al.* (2009) have shown that the use of radar data for an urban hydrological study required a new local adjustment between radar and rain gauges to be completed beforehand. Therefore, a new factual adjustment has been done between radar data and the ones of the 6 rain gauges of the SIAVB.

3.3 Selected rain events

6 rain events of various types, recorded in 2007 and 2008, have been selected. Two different types of events can be distinguished:

- events of February and April 2008, characterized by a small rain accumulation (from 10 to 11 mm per event) and a small spatial variability;
- events of August 2007, May, July and August 2008 with highest rain accumulations (up to 34 mm per event) and which are very heterogeneous spatially.

The objective of this work is not to study the spatial variability of the rain events (Schilling, 2004), but to assess by means of a limited number of case studies, if the availability of radar images is able to provide a significant benefit for hydrological modelling in comparison to the actual rainfall measurement network.

3.4 Model used

HydraRiv® is a dynamic simulation chain of the hydraulic flows, developed by the engineering company of Hydratec. This model can be either forced by data from rain gauges or by spatialized radar data. Moreover, it opens the possibility of taking into account the retention basins in the simulation or of considering them transparent (full).

3.4.1 Hydrological module

The hydrological module computes the discharge inputs at a point of the principal network from rainfall data, from the characteristics of catchments located upstream of this point and from the geometric data of the collectors leading to this point. Computations have been done on each catchment to obtain the hydrograph at their outlet and are in the chronological following order:

- computation of the rainfall falling on the catchment from the 6 rain gauge data sets or using the radar data. The interpolation method by distance weighting has been used for the rain gauge data. For the radar data, the intersection between the catchments and the radar pixels allowed the rainfall intensity of each catchment to be determined;
- computation of the net rainfall by the runoff coefficient method;
- transformation of rainfall to flow by the linear reservoir method.

At the end of the computation, the routing of the runoff hydrograph between the outlet and the point of the principal network is described by the kinematic wave scheme.

3.4.2 Hydraulic module

HydraRiv® opens the possibility of two different representations of flows:

- flow along a river reach or inside a floodplain. This type of flow is described by the Saint-Venant equations or by a system of equations with partial derivatives for the singularities;
- storage zone in the floodplain characterized by a small mean speed. In such a zone flow transfers are conditioned by some exchange boundary laws. This representation is mainly used for the retention basins. When they are taken into account, a local regulation is defined for each retention basin.

The both representations are connected together by lateral extern links.

3 historical rain events have been used to calibrate the hydrological and the hydraulic parameters of the model (response time and runoff coefficient of the catchments, Strickler coefficients and curves of the rivers).

3.4.3 Model outputs

Flows are computed at the 6 following critical points: "Trou salé", "Arcades", "Vauboyen", "Monseigneur", "Golfy" and "Cambacérès" (Figure 2).

4 RESULTS

4.1 Efficiency of retention basins

To study the influence of retention basins on the discharges, the simulation of flows has been done according to two configurations: presence or absence of retention basins. In both cases, the model has been forced with the 6 rain gauge data which are the only data quantitatively used by the SIAVB.

Figure 3 shows clearly that retention basins play an important role by storing a part of the flows (from 8 h). Their presence engenders a significant decrease of the flows and, notably, of the peak flow which is reduced by about 50%.

For the 6 events, we have computed at each critical point the mean ratio between water volumes with and without basin in order to estimate quantitatively the impact of retention basins (Table 1). On an average, the flows are reduced by 23% but with high discrepancies linked to the location (variation from 2% to 45%). The retention basin located upstream, to the critical point of "Trou Salé", and those located upstream to "Golfy" are respectively the basins having the lowest and the highest influence on the flows.

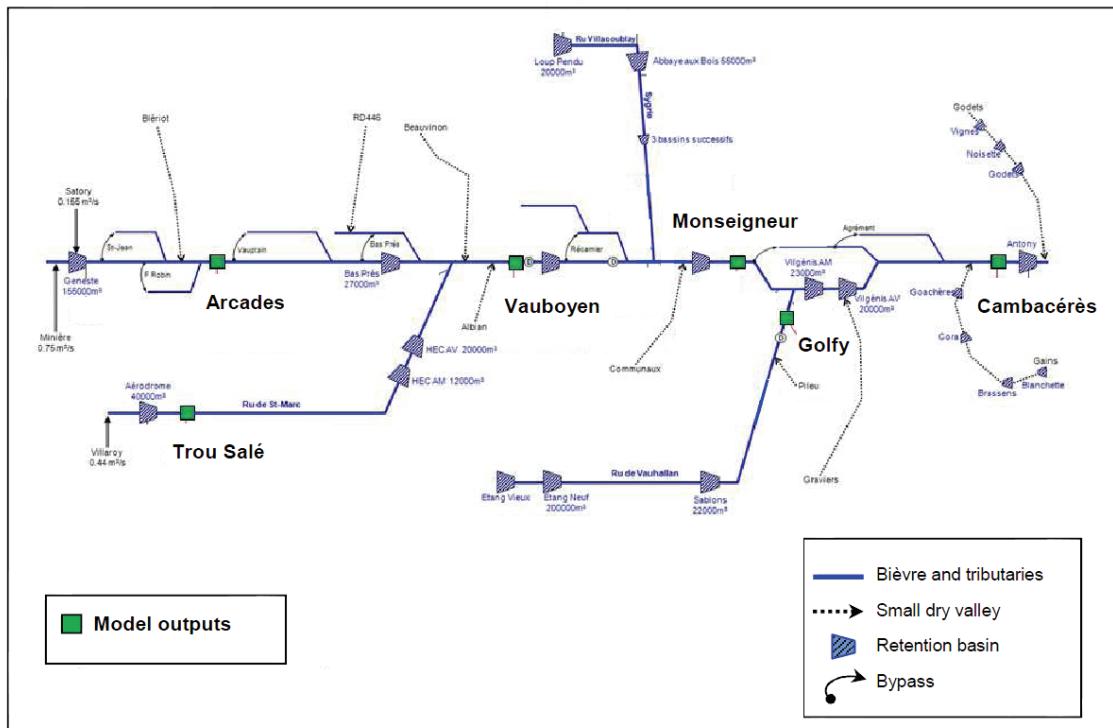


Figure 2: Location of the model outputs (6 critical points) on the longitudinal profile of the catchment. The retention basins are indicated by the hatched lozenges.

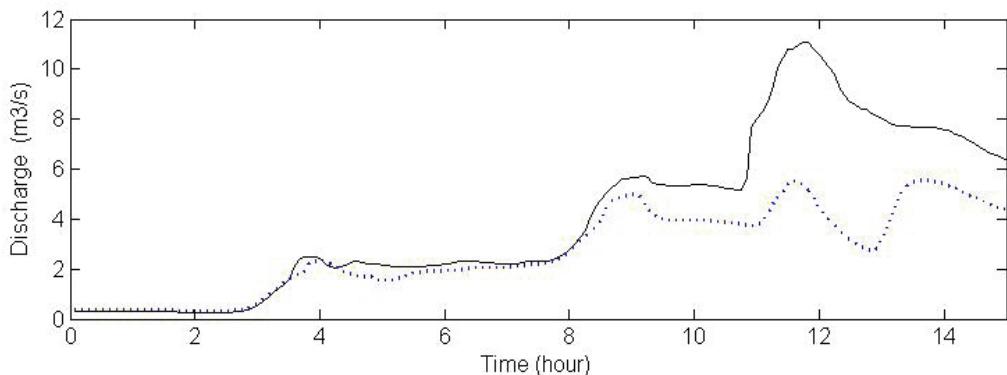


Figure 3: Hydrograph simulated by taking into account (dotted line) or not (solid line) the retention basins at the critical point "Cambacérès" during the event of August 2007.

Critical points	Volume of flow without retention basin / Volume of flow with basin
Trou Salé	1.02
Arcades	1.25
Vauboyen	1.21
Monseigneur	1.18
Golfy	1.83
Cambacérès	1.26

Table 1: Mean ratio over the 6 events at the 6 critical points between the volumes of flows without retention basin and those with basin.

4.2 Contribution of radar measurement

The spatialization component of the precipitation has been assessed by comparing the real hydrographs to the ones simulated by the model forced with:

- rainfall radar images (*i.e.* one data point every km^2 , case 1);
- radar data made equivalent to the 6 rain gauges (case 2): only the radar pixels corresponding to the 6 rain gauges are used. These data are interpolated by distance weighting in order to create a map of rain intensity. Therefore, the only effect of spatialization is studied here.

Results of the different simulations show that the difference between the discharges computed from spatialized radar data (case 1) and the non-spatialized ones (case 2) is very small (*Figure 4*).

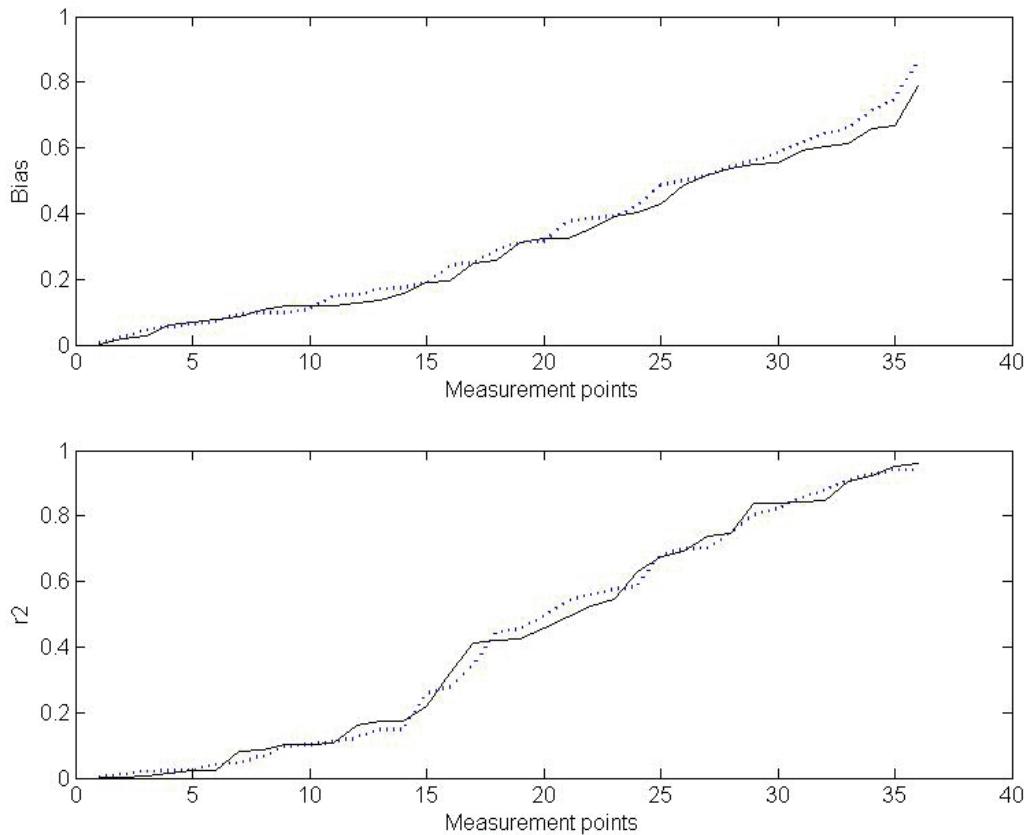


Figure 4: Efficiency curves of the Bias (above) and of the determination coefficient, r^2 (below). At each critical point (a total of 6) and for the 6 events (a total of 36 points), the Bias and the r^2 have been computed between the real discharges and the discharges simulated by the model either forced by the non spatialized radar data (dotted lines) or by the spatialized radar data (solid lines) and then ordered in an increasing way.

So, for the 6 studied events, a detailed knowledge of rainfall (every km^2), compared to a knowledge restricted at 6 points (corresponding to the location of the rain gauges), does not improve the discharge simulations of the upper part of the Bièvre catchment. A possible explanation is that the rainfall information given by the 6 rain gauges is sufficient to simulate in a satisfactory way the discharges at the critical points. This assumption is supported by the results obtained by Berne *et al.* (2004) who proposed a quantitative basis to the requirements about space-time resolutions for rainfall measurement dedicated to urban applications, however in a different (Mediterranean) climatological context. To verify this assumption, the model has been forced according to the two following methods:

- with the radar data taken at the location of the 6 rain gauges (as previously, case 2);
- with the radar data taken at the location of 3 of those 6 rain gauges, that is to say “Geneste” (located upstream), “Loup Pendu” (in the centre) and “Villgénis” (at downstream) (*Figure 1*). This assumption corresponds to the removal of the 3 other rain gauges.

Figure 5 presents the real hydrograph (dotted line) and the ones obtained according to the two different methods at the critical section “Monseigneur” during the event of April 2008. Significant differences can be noted down. The simulation of discharges, using only 3 measurement points, gives the worst results. The peaks of the real discharges (at respectively 4 h and 6 h) are well simulated when 6 measurement points of rainfall are used. On the other hand, they disappeared when only 3 measurement points of rainfall are used. Moreover, from the 19th hour, the gap between the real discharges and the discharges simulated using 3 points becomes very important. This significant gap might be due to a more intense rainfall at those 3 rain gauges locations from that moment on. So, the spatialization of the information given by the 3 rain gauges overestimates the real rainfall. Those results show that 3 rain gauges are not sufficient to cover correctly this catchment.

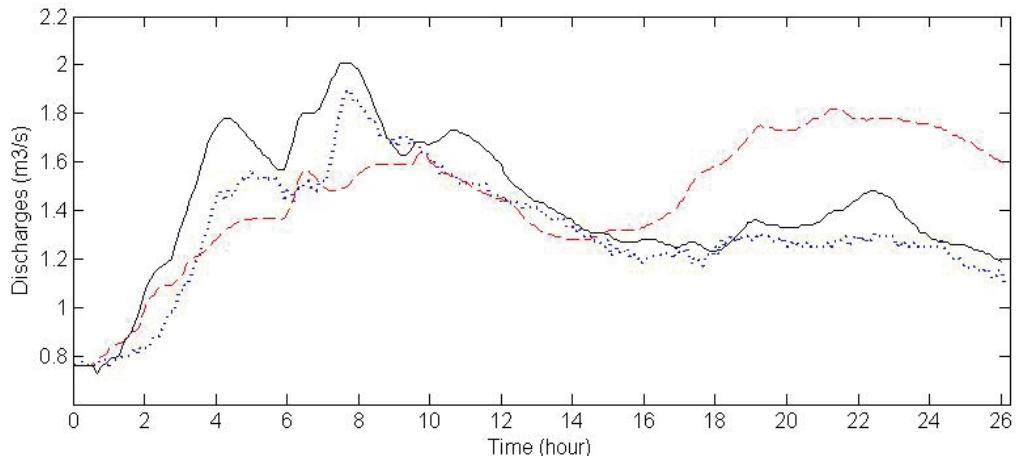


Figure 5: Real hydrograph (dotted line) or simulated using radar data taken at 6 points (solid line) or simulated using radar data taken at 3 points (dashed line) at the critical point “Monseigneur” during the event of April 2008.

For the 6 events and at each critical point, the simulated discharges from rainfall data taken at 3 points are significantly different from the real discharges than those simulated from the rainfall data taken at 6 points (r^2 highest, *Figure 6*). So, the 6 rain gauge network of the SIAVB gives reliable information of rainfall, information not given by a less dense network. In the case of a 3 rain gauge network, the spatialization of radar data could give us this missing information (*Figure 6*).

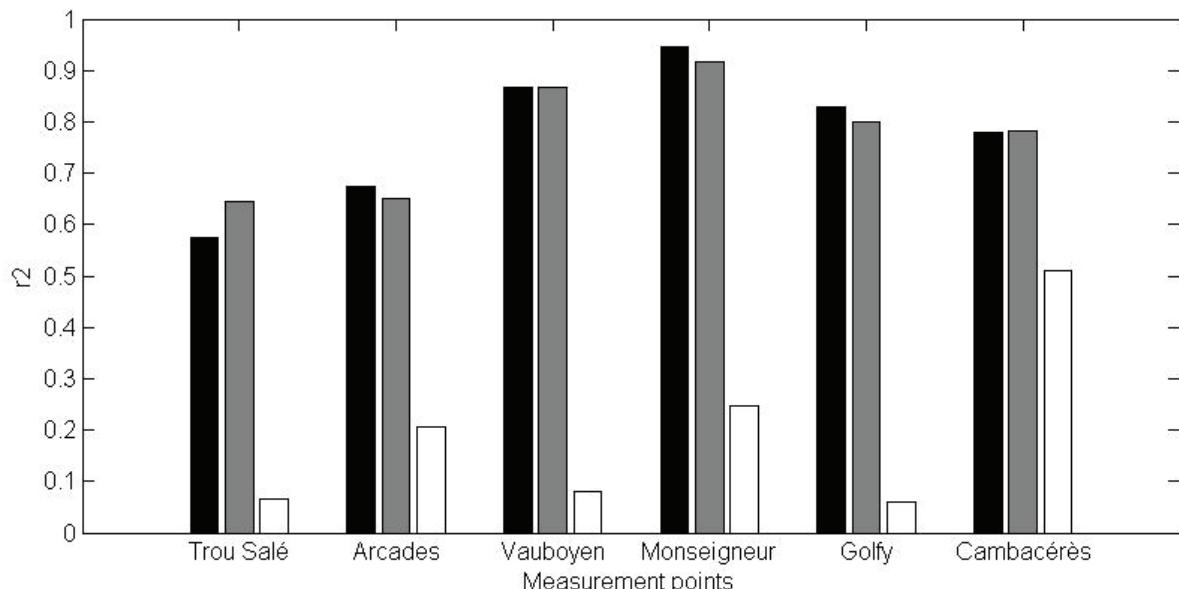


Figure 6: Evolution of the determination coefficient (r^2) computed between real and simulated discharges by the model forced by the spatialized radar data (in black), by radar data taken at 6 points (in grey) and taken at 3 points (in white) at the 6 critical points.

5 CONCLUSION

This study has been carried out in a well defined operational context: a catchment of 120 km², equipped with retention basins, 6 rain gauges, numerous flow stations and covered by the weather radar of Trappes. The main goal was to assess the efficiency of retention basins regarding the flow decrease and to study, in such a context, the quantitative interest of the radar data characterized by a high spatial resolution (1 km²). In this view, a distributed hydrological model [HydraRiv® (Hydratec Company)] has been used to assess several scenarios during 6 rain events. Results have shown that retention basins engendered a decrease (from 2% to 45%) of the discharges in function of the flow measurement point. Moreover, for the Bièvre catchment and for the 6 studied rain events, spatialized radar data compared to data taken at only 6 points (corresponding to the location of the rain gauges of the SIAVB) do not significantly improve the discharge simulations and so do not enable an improvement of the management of rainwater. An advanced explanation is that the 6 rain gauges of the SIAVB properly cover this 120 km² catchment. Indeed, if the SIAVB had only 3 of those 6 rain gauges, the information given regarding the knowledge of rainfall intensities would not allow an adapted management of this catchment. To complete this work, it would be of interest to simulate a higher number of rain events to strengthen our results but also to transpose this methodology on other catchments having different characteristics.

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