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INTEGRATED FLOOD MANAGEMENT APPROACH TO COMBINE URBAN GENERATED FLOODS AND ECOSYSTEM SERVICES PRESERVATION.

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ABSTRACT: This article exposes a strategy for managing flood risk that would be implemented in areas that are prone to rapid urban expansion. We take here the opportunity of a well document periurban watershed (150 km2) located in the vicinity of Lyon city (France) and where large investments from national, regional and local authorities have been devoted since 2008 to reduce urban pollution sources and the hazard of hydrological extremes, flood and drought. These actions contribute to restore lost ecosystem services like bio-assimilation and transformation of organic substances improving global surface water quality, human health and providing societal economic benefits. Predicted urban development would however compromise these efforts in the near future. It means that rapid periurban development should integrate both flood management risk it generates for near densely urban system it grows around and preservation of new stream water ecosystem it affects.

To address this issue, we develop on this periurban watershed a probabilistic based hydrological modeling of its flood regime. Only the landscape change is considered at this stage, arguing here that climate change will have less impact on the mid-term horizon of 2030. Main working hypothesis is to assume on-site rain water retention implementation for new constructions expected on 2030. This is to increase flexibility in controlling urban floods. A constraint is however to maintain occasional overflows from sewer systems to ensure protection of downstream dense urban areas against pluvial flooding. At the same time we consider to prevent receiving stream ecosystems from geomorphic and water quality damages as to keep ecosystem services working.

Key Words: Urban expansion, Urban flood, Full bank discharge, Stream-bed incision, Aquatic ecosystem, Storm water source control, City of Lyon (France)

1. INTRODUCTION

Urban systems results in more surface runoff of rain water and to a rapid evacuation of this water through urban sewer network to receiving surface water bodies. It results in a now recognized water ecosystem impact with connected services reduction and socio-economical and human health implications due to limitation of local water resource exploitation. The usual way of urban storm water management is now perceived as a weakness in front of three rising challenges which are:

- The structural degradation of ageing assets which reduces their flowing capacity as a result of persistent ground-water drainage in some parts of a sewer network. This induces more frequent overflows from rainfall and combined sewer systems, discharging polluted waters into streams or directly flooding over urban streets from man-holes. Because main collectors are often located along natural stream courses they partly drain groundwater that should normally feed these streams. A sensitive and measurable consequence is the reduction of water availability sustaining low flows and then limiting natural dilution capacity and increasing pollution impact (Braud et al., 2012).

- The worldwide trend in urban population growing (UNFPA, 2007) is reflected by a rapid expansion of cities which contributes to increase imperviousness and requires by the way more rain-runoff control (Wagner & Breil, 2013). Centralized sanitation system where sewer waters are going to main waste water treatment plants are becoming progressively undersized but the flow amount coming in is also limited by sewer network carrying capacity which cannot be rebuild at an affordable cost. To face this issue a decentralized strategy for managing rainfall waters is progressively gaining interest. On-site rainfall water management using infiltration possibilities or detention/filtration basins to get cleaned water back to stream courses at a natural rate and sustain flowing during low flow periods are now promoted in new building areas. The objective is to collect mainly grey and dark waters into existing combined systems and to convey these waters to a centralized treatment plant. The effect is to limit temporary excess of water and then avoid discharging of polluted waters from sewers to natural systems. This can be implemented mainly in new build areas both in urban expansion and urban retrofitting operations. A main lack for decision makers today is getting a clear idea of expected results both in terms or urban storm-water management in the city and in terms of impact reduction on receiving water ecosystems and related services. Technical and legal aspects have to be addressed before going a step forward regarding for example in Europe the water framework directive forcing objectives for European water masses (EWFD, 2000);

- The predicted harsher rainfall regime due to global climate change will affect some very populated parts of the earth. It should result in more frequent occurrence of intense rainfalls. This evolution will increase sewer system solicitation and overflowing because these assets were sized using statistics from rainfall time series observed over the last century. Mean annual temperature increasing should also induce more biofilm development into sewer systems (Breil et al., 2013) providing more pollution loading in overflows going to natural receiving waters. Also predicted longer dry sequences should contribute increasing severity of low flow periods on streams and rivers decreasing their ability to dilute and bio-assimilate urban organic pollution delivered by sewer overflows during storm events.

Then the need for a new management strategy integrating both urban flooding control and reduction of urban storm water impact on receiving water courses or standing waters is urgently required.

First challenge is considered in face of the financial capacity of communities. Its high cost remains a barrier to improve and renovate existing-old sewer networks and methods for setting priority criteria are required. This is the case for example in the USA – through the Clean Water Act (CWA, 1972) - by imposing a given authorized maximum rate of combined sewer overflow (CSO) to natural mean flow of the receiving river, ensuring a given rate of dilution. Such policy directed big investments towards CSOs and connected sewer renovation developing storm water buried tanks, disconnecting on possible rain runoff from combined sewers. These rules exist for a long time also in most of the developed countries when building a sewer system but the fact is the urban runoff production areas have now increased over planned development which was based on one or two decades only. This fate was confirmed in an extensive study (European project REBECCA, 2006) where one of the objective was inter-scaling of bio-monitoring methods between selected regions in Europe and considering in each one 16 land use types from the CORINE land cover EU database. While not being the purpose of this work a main output was the highest negative correlation between all indexes and the “discontinuous urban” land cover. This result clearly indicated this land cover type was harmful for aquatic ecosystems quality in relation to most uncontrolled urban overflows than in dense and historical urban settlements where sewer systems are better maintained due to financial and technical capacities.

Second challenge is addressed looking at rainfall runoff control at source with several possible fates (delaying, infiltration, storing for non-drinking water uses) which seem to be a realistic opportunity. However its global efficiency, durability and maintenance cost remains quite unknown which is crucial before decision makers support it as a new long term strategy for urban storm water management principle.

Third challenge clearly indicates that urban rainfall flooding will increase and that decisions must be taken by now. From these trends we predict more urban flooding and more natural ecosystem services degradation.

In this paper it is intended to propose a methodology considering the presented three issues. This method is implemented on a well document watershed exhibiting a spatial and temporal gradient of urbanization.

2. MATERIAL AND METHOD

City of Lyon welcomes today 1.4M inhabitants and is expected reaching 1.7M by 2050. Past urban expansion is well shown on figure 1. The spreading of the urban (light grey) area inside and outside the administrative city boundary (thin white line) is tangible from year 1975 to year 2000. Peripheral - also named periurban - expansion is well illustrated with the aggregation of urban nucleuses. Land conversion from rural to urban has implication on the flow regime of small to medium size watersheds. This is the case for the Yzeron basin (bold white line) which is 150 km2 at its outlet (white circle) and which is globally flowing west to east before joining the large river Saône River. From a recent research program partly dedicated to land use conversion (Braud et al, 2011) it was observed using aerial photography taken on 1970, 1990 and 2008 that percent basin artificial area (impervious but also public gardens) was respectively of 21.4, 32.8 and 36.6 (Jacqueminet et al., 2013). These data clearly indicate how urban pressure has increased from a fifth to a third over forty years. It is noticeable from figure 1 that mainly the basin downstream part is concerned by the urban expansion process. It is also where urban flooding takes place with more frequent inundations in the last decade. It was concluded from hydrological modeling and statistical tests that both urban development since the seventies and a rainfall regime change towards more concentrated rainfalls over several days in the nineties were the reasons for the observed increasing in flood frequency (Radojevic et al. 2010).

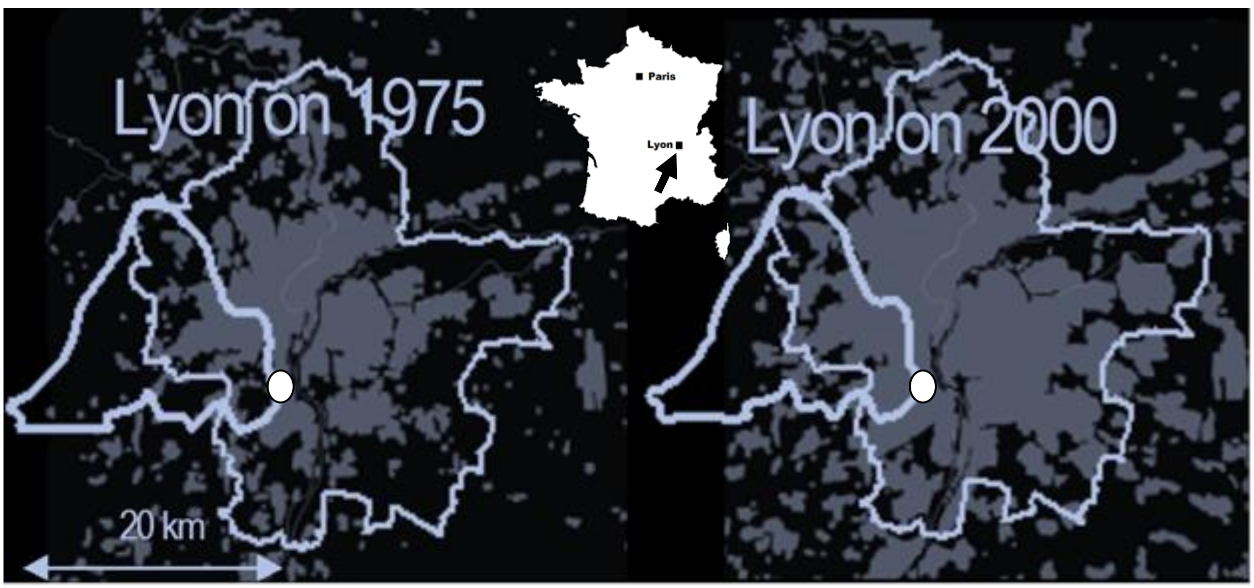


Figure 1: Urban expansion process for the city of Lyon (France)

The Yzeron basin is considered as a pilot basin for developing integrated water resource management in face of urban development and climate change. An integrated approach for managing water and ecological quality and hydrological extremes is designed since 2007 and progressively implemented. There are three main goals which are flood control, low flow resource sharing and good ecological quality maintenance. They are all interrelated because normal flow range - here considered range between the 2-year flood peak and the 2-year minimum monthly flow – is affected both by urban storm water overflows, groundwater drainage by sewer network (Braud et al, 2013) and irrigation activities in the upper basin part.

The downstream basin part protection against large floods generated by the two third upstream part of the basin is considered by authorities implementing two large empty (dry) dams (Radojevic et al, 2012).

Then the purpose of this paper is then not in the flood management strategy of the downstream part of the Yzeron basin but fully in its periurban upstream part where most of the future urban development is now projected. The corresponding area is about two third of the whole basin. In this view, integrated flood management is here considered managing both urban storm water runoff and ecology of receiving waters as to preserve related ecosystem services (MEA, 2005). A main concern is to evaluate the potential efficiency of urban rainfall runoff control at source in mitigating urban CSOs harmful consequences on river ecology. To reach this goal the following steps are implemented.

2.1 Modeling Of Rural And Urban Flood Peaks

Method for modeling the combined effect of urban overflows (CSOs) and natural flood on small basins of some squared kilometers is presented in details in another article (Navratil et al, 2013). It is roughly based on a probabilistic modeling of a flood regime. Probabilistic law is first fitted from a regional analysis of flood characteristics extracted from flow time series collected in the area of interest (Galea & Prudhomme, 1997). This modeling approach allows prediction of flow-frequency-duration curves (called QdF models) at ungauged rural basins from 1 to 10 000 km2 overall. To extend this limit, an adaptation of QdF modeling was developed (Galea & Ramez, 1995) to address the fast runoff response of small basins ranging from some hectares to some square kilometers and exhibiting steep slopes and bare soils. For the convenience in this study this last version is called QdF-urban when the primer is called QdF-rural.

A first hypothesis (H1) is to consider that QdF-Urban allows prediction of urban runoff. A second hypothesis (H2) is to consider that for small basins, less than 10 km2, flood peaks from rural and urban components are concomitant and can then be summed to calculate their combined effect.

H1 and H2 are tested using recorded data from an experimental catchment of 2.7 km2 located in the Yzeron basin. This basin is quite representative of the rapid periurban development in the west of Lyon city. Its urban area occupies around 10% of its downstream part. Its combined sewer system is equipped with a first CSO (Combined Sewer Overflow) outlet where gauge stations are installed. Flow data are recorded since1997 at a one minute time step at three locations: directly in the CSO outlet and just upstream and downstream the CSO device in the stream course which receives the overflows. This experimental design allows extracting of flood statistics from the urban overflow and from its combination to natural flows directly in the stream. Flood peaks are extracted following the Peak Over-Threshold (POT) method (eg Stedinger et al., 1992) from the three flow time series using an automated sampling procedure ensuring selected flood events are independent from each other. Sampled flood peaks are then attributed an empirical return period using the empirical frequency proposed by Chegodayev (or Bernard and Bos-Levenbach) which is considered as one of the less biased formula (Rosbjerg *et al*., 1992). Observed and modeled data are then compared to assess the capacity of QdF modeling to represent CSOs and their combination with natural floods in small streams with are often impacted by urban storm-water overflows.

In a second stage, QdF-rural model is fitted for the Yzeron basin using the method described in Galea and Prudhomme (1997). Model is ran at 45 sub-basins outlets which were selected in another study (Jacqueminet et al. 2013) considering a variety of projected land use development in combination to a range of sensitivity of their draining stream to incision process. Stations features are described in table 1. The set covers a range from 0.18 to 6.17 km2. The objective is here to consider also stream bed exhibiting an incision process which would exacerbate with urban development. This choice is made because in addition to water quality degradation due to CSOs there is also a physical degradation caused by stream-bed incision, inducing river bank collapsing and fine material deposits with possible clogging or unmarking effects on downstream water courses with consequences for biota and related ecological services.

For the purpose of this study it is considered a single overflow device located at the outlet of each sub-basin. It is also considered that combined sewers are designed to keep part of the urban runoff which does not be added to rural runoff at the outlet when summing rural and urban components. To handle this storm weather extra-flow sewer systems where (are) usually designed to carry five folds the equivalent dry weather –domestic flow production. This is done considering planned population development on a twenty years period. To calculate the storm-flow which is kept by an existing sewer system it is then considered the domestic flow rate per unit of urban squared kilometer. Using experimental sub-basin data (population, urban area connected to the combined sewer, measured dry weather discharge in the sewer) it is calculated an average production of 0.012 m3 s-1 km-2.

Considering this sub-basin habitat is representative of a periurban zone with residential lots developing around old villages and with some new small buildings, this production rate is used for all the other sub-basins. The overflow discharge threshold is then obtained multiplying five folds the corresponding calculated domestic flow rate on 2008. This threshold value is subtracted from the QdF-urban values used to predict the urban runoff going to the combined sewer system. The remaining part when it exists corresponds to the combined sewer overflowing. This part is added to QdF-rural prediction to consider the effect of urban storm water overflows on the natural flood regime.

The 2-year flood peak modeling is first run without considering any urban area as to get a picture of the natural flood peak value. In a second time, this is done including present and future urban development and finally considering the limitation of new urban runoff flow at 0.5 m3 s-1 km-2 for newly created impervious areas. This flow rate condition must be fulfilled till the 30-year rainfall event

2.2 Prediction Of Stream-Bed Incision

Bed incision process in little streams is known to relate with urban runoff (Gregory, 2002). Incision has several detrimental effects on the aquatic ecosystem like substrates clogging, groundwater depletion and increased groundwater sensitivity to surface water pollution (Miltner et al., 2004). This geomorphological process was related in another study on the Yzeron basin to the presence of urbanization development and CSOs outlets (Navratil et al., 2012). The two years return period flood peak (2y_flood peak) was demonstrated to well figure the bank-full discharge (BFD) at 17 small streams located in the Yzeron basin with draining areas ranging from 0.2 to 33.9 km2. Using these published data two new linear models are proposed to calculate (Eq. 1) a natural BFD and (Eq. 2) a urban BFD from the 2y_flood peak as follow:

Ln(BFD) = 1.31 * Ln(2y_flood peak) - 0.12 R^2=0.93, n=7 [Eq. 1]

Ln(BFD) = 1.43 * Ln(2y_flood peak) + 0.22 R^2=0.93, n=10 [Eq. 2]

Table 1: Sub-basins features and % urban area at present and future.

Site id.	Basin area (km2)	Stream bed with incision	%urban area 2008	%urban area 2030	Site id.	Basin area (km2)	Stream bed with incision	%urban area 2008	%urban area 2030	Site id.	Basin area (km2)	Stream bed with incision	%urban area 2008	%urban area 2030
1	2.27		0.25	0.38	**16**	2.11		3.96	8.73	**31**	0.51		6.17	16.58
2	5.78		1.11	2.42	**17**	3.08	x	3.58	11.95	**32**	0.77		2.48	6.01
3	2.04		0.29	0.26	**18**	2.98		1.84	5.50	**33**	0.26		0.00	0.00
4	1.11		0.18	0.05	**19**	1.20	x	14.32	25.39	**34**	0.35		3.35	9.43
5	0.59	x	0.00	0.01	**20**	2.15		1.99	5.00	**35**	4.88		0.73	1.22
6	1.33		0.09	0.18	**21**	4.04		0.77	2.40	**36**	3.94	x	12.75	27.62
7	0.27		2.35	5.40	**22**	0.77	x	0.43	1.80	**37**	0.72		13.36	29.47
8	2.40	x	0.71	1.54	**23**	2.96		3.43	18.92	**38**	0.18	x	26.61	49.06
9	3.49		0.85	1.96	**24**	0.67		2.47	8.59	**39**	0.36		44.61	59.88
10	3.18		0.02	0.18	**25**	1.72	x	9.34	21.48	**40**	0.64		27.20	51.05
11	2.10		1.66	4.48	**26**	0.52	x	2.78	10.42	**41**	0.70		0.23	0.43
12	3.62	x	8.91	18.53	**27**	1.59	x	21.49	35.83	**42**	1.98		6.78	23.91
13	3.56	x	0.68	2.37	**28**	3.09	x	5.53	18.77	**43**	0.90	x	14.97	34.29
14	5.63		1.59	3.66	**29**	0.32		7.72	20.53	**44**	0.32		24.14	44.98
15	6.17		1.74	4.26	**30**	0.59	x	20.18	36.57	**45**	0.19	x	13.72	24.09

objective of this study is then to test a method as to compare simulated Bank Full Discharge (BFD) at natural state with simulated values including present (2008) and future (2030) urban development scenario and finally considering the effect of urban runoff limitation control in the 2030 scenario.

Comparisons between scenarios are made using ratio of BFD with different urban development scenarios (using Eq.2) to BFD "true" rural scenario used as a reference situation. It is calculated using Eq.1. BFD ratios are used to judge about a criteria for detecting from which ratio stream-bed incision process can start indicating when detrimental effect of CSOs would occur. This ratio is then used to judge of the potential effect of managing rainfall runoff in avoiding these detrimental consequences for aquatic ecosystems.

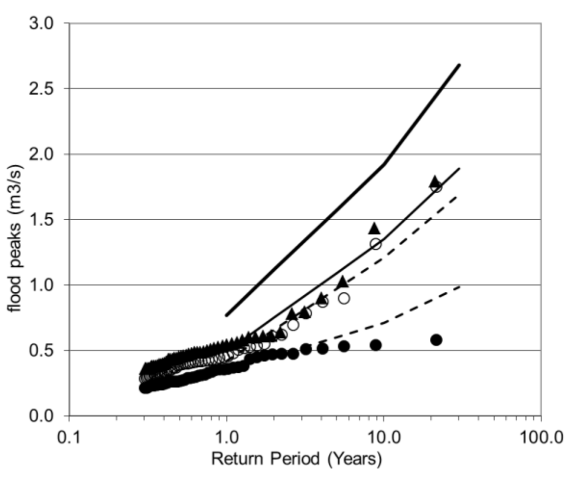
3. RESULTS

3.1 Setting -Rural And -Urban QdF Models To Predict Flood-Peaks In The Yzeron Basin

QdF models are tested using recorded flow times series running from 1997 to 2013 and monitored on an experimental sub-basin of the Yzeron. Recorded time series correspond to (1) natural stream flow upstream the CSO outlet, (2) CSOs events and (3) natural plus CSOs flows recorded downstream the CSO outlet in the stream. Regional parameters for the Yzeron basin where calculated in the frame of other published works (Radojevic et al., 2010, Navratil et al., 2013). They correspond to the following parameters:

- Mean annual rainfall (mm)
- 10_years return period daily rainfall (mm)
- Mean annual temperature (°C)
- 10_years return period rainfall amount cumulated on the concentration time duration (mm)

The last parameter is used in QdF-urban modeling when the others are dedicated to QdF-rural modeling. Then when QdF models are fitted the only data required to get predicted flood peaks is the sub-basin area which allows scaling of QdF models. Control for QdF-models is illustrated in Figure 2.



The Figure 2: QdF-rural and –urban models (lines). Flood peaks (dots) for CSOs (dark circles), natural flow (white circles) and total flow (dark triangles).

POT sampling method extracts greatest independent floods from a flow time series. It is performed in this study to get at least on average 3 values a year over the period of record. This sampling design allows getting the minimum return period of 0.33. Maximum return period is about 20 years given the time series duration and the empirical frequency used formula.

A first consideration is to note that for a 10% urbanized area like in this small basin (2.6 km2) the magnitude of CSOs peaks varies from 0.75 of natural flood peaks for the 2_year return period to 0.6 for the 20_year return periods. CSOs peaks (black circles) are in the range of 0.2-0.5 m3/s in this frequency domain. Increasing of CSOs peaks seem to stabilize around 0.5 for return period over 2 years. It can reveal structural limitation of the sewer network upstream the CSO device for large rainfalls which can result in transient storage of urban runoff over impervious surfaces.

This is overall very case dependent and it is assumed in this study to consider the corresponding QdF-urban modeling prediction fits well with observations till return period of 4 years in that case. Observed natural (white circle in Fig.2) and total flood peaks (dark triangles in Fig.2) are closed together. This means that CSOs and natural flood peaks do not fully sum and are then not concomitant in time. The explanation is that urban runoff response time to storm events is very rapid comparing rural hydrological response even for small basins of some km2. Concerning models, QdF-rural model (upper dashed line) is also well fitted with data for the natural flood peaks. Finally to simulate the combined effect of QdF-urban and QdF-rural it is not possible to add flood peaks of same return periods. The corresponding model is illustrated by the upper bold plain line. The thin plain line assumes summation of 100% natural and 20% CSOs contributions to figure lack of concomitancy between flood peaks. This model is retained to simulate 2-year peak floods with contribution of urban floods and then calculate BFD evolution with urbanization using Eq.2.

These results validate and confirm the modeling approach which is then assumed to work properly for the 45 ungauged basins of this study.

3.2 Full Bank Discharge Evolution With Urban Development

Flood peaks are simulated using QdF-rural and –urban (see § 2.1) at each sub-basin outlet (see Table1) with results for return periods of 0.3, 1, 5, 10 and 30 years. To get a natural reference, BFD is calculated from rural 2_year flood peaks with Eq.1. In that case it is assumed %urban is zero on sub-basins. Urban 2_year flood peaks are used in Eq.2 to calculate BFD on 2008 and 2030. Ratio of FBD-urban to FBD-natural is calculated to control for the evolution of BFD with urban development. At this stage sub-basins presenting bed incision (see indication in Table 1) are of particular interest to judge from which BFD ratio this process can start.

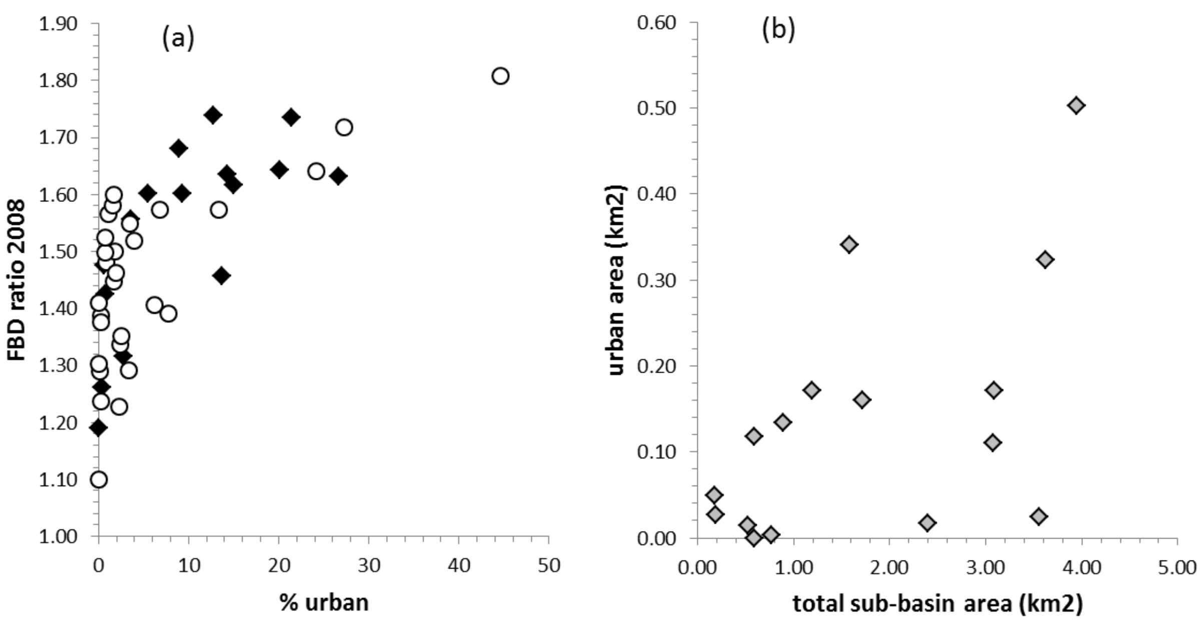


Figure 3: (a) Calculated 2008 FBD ratios at sub-basin outlets VS % urban for stream without bed incision (white dots) and observed active incision (black dots). (b) Urbanized sub-basin area VS total area for stream with incision only.

Plot of BFD ratios against %urban (Fig 3a) for year 2008 reveals that urban rate not fully discriminate sub-basins showing stream bed incision from sub-basins with no incision. However a trend with greater ratios seems to emerge overall. As it is illustrated by Fig.3b the 3 near zero %urban values correspond to sub-basins of less than 1 km2.

A box plot representations help to figure statistical distributions of BFD ratios (Fig 4). Ratios are compared between Incised (Y) and not incised (N) sub-basins groups. Comparison of 2008 to 2030 illustrates how predicted urban development would impact ratio distributions with a noticeable increasing in all distributions excepted for the lower point of incised group (Y) for which corresponding sub-basins will stay in natural condition (see Table 1, site n° 5). Median values for group (N) increases from 1.46 (2008) to 1.55 (2030) and for group (Y) from 1.60 to 1.76. Because these groups show free distributions (not normally distributed) and small number of individuals the Kolmogorov-Smirnov non-parametric comparison test is used with a two sided probabilities making no hypothesis on the direction of ratios evolution between groups. It evaluates probability level of distribution similarities. For 2008 probability (P) is P=0.019 between groups (N) and (Y). It is of P=0.042 for 2030. Then a significant difference ($P <= 0.05$) is confirmed between BFD ratios of incised and not incised sub-basins opening possibility for detecting a ratio from which incision is induced by urban development.

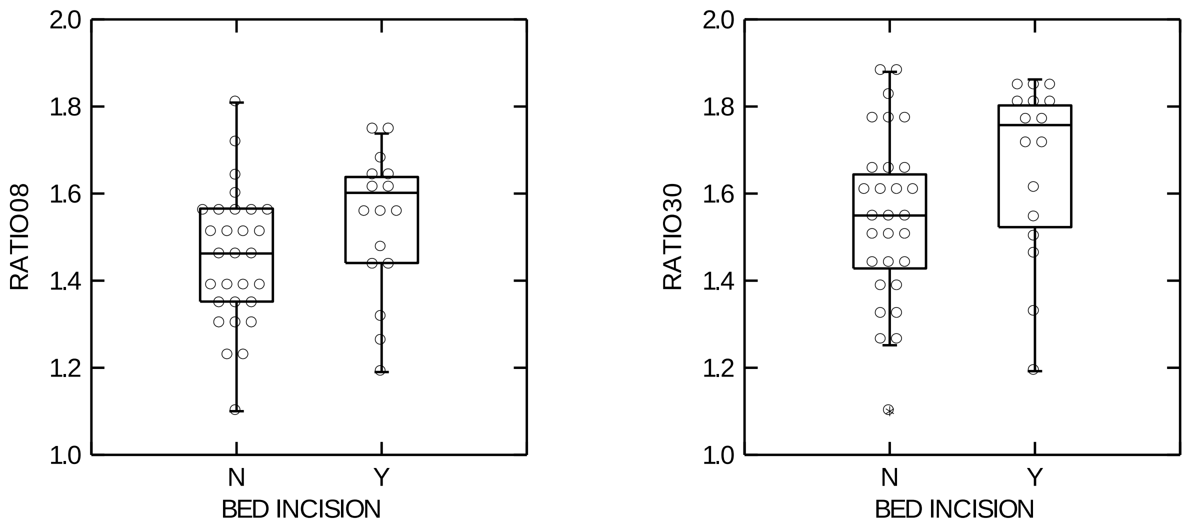


Figure 4 a, b: Box plot of calculated BFD ratios at sub-basin outlets respectively on 2008 (a) and (b) 2030. Two groups are considered: group 'Y' for incised stream bed and group 'N' for not incised stream bed. Boxes show quartiles 25%, 50%, 75% and lines bottom give 1.5 fold the inter range of upper and lower quartiles (stars indicate 3.0 folds inter range limits). Dots figure density distribution of data.

3.3 Full Bank Discharge Evolution Including Urban Runoff Control For New Constructions

To consider the effect of new building rules on BFD ratios since 2008 it is assumed that additional urban runoff is limited to 0.5 m3 s-1 km-2 of impervious connected area. A box-plot of BFD ratio distributions allows a graphical comparison (Fig 5). To test this 2030 scenario the 2-year QdF-Urban and -Rural are calculated using 2008 %urban and 2030 %rural but considering the additional domestic flow in QdF-urban and the additional constant runoff provided by new build areas using new runoff control technologies in QdF-Rural.

Ratios for incised (Y) and not incised (N) stream-bed groups are shown. It can be noted that median value of third box (right side – 2030 with runoff control) for each group is lower than median value (2030 without runoff control) of central box. It confirms the effect of urban runoff control on BFD ratios in each group. The effect seems more performant for not incised group (N) with a ratio distribution not far from what it is observed on 2008 (left box).

Again the Kolmogorov-Smirnov probability test is used to get a quantified estimation of observed differences (Table 2). Group N shows no significant differences between its ratios distribution all over when is it very significant (P <= 0.01) between 2008 and 2030 without runoff control. No significant effect of runoff control (ratio 2030+) is detected with ratio 2030 indicating this strategy would have no sensitive consequences on the reduction of new incised sub-basins at least.

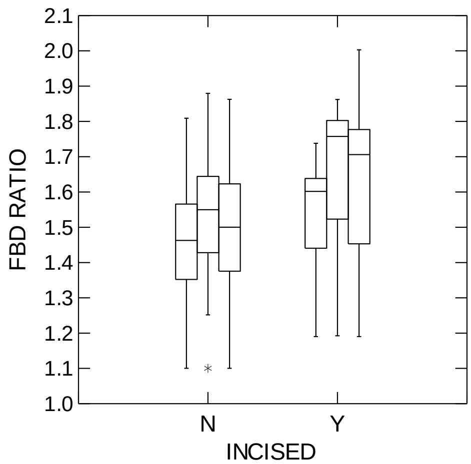


Figure 5: Box plot of calculated BFD ratios at sub-basin outlets. There are 3 boxes by group (Y and N) from left to right for 2008 and 2030 managing runoff “as usual” and 2030 considering new rules for managing rainfall runoff. Two groups are considered: group ‘Y’ for incised stream bed and group ‘N’ for not incised stream bed. Boxes show quartiles 25%, 50%, 75% and lines bottom give 1.5 fold the inter range of upper and lower quartiles (stars indicate 3.0 folds inter range limits).

Table 2: Probability level of Kolmogorov-Smirnov non-parametric test to compare FBD Ratios evolution by groups (Y and N) and considering new rainfall runoff management effect (2030+)

	group N		group Y	
	RATIO_08	RATIO_30	RATIO_08	RATIO_30
RATIO_30	0.107		0.006	
RATIO_30+	0.738	0.521	0.065	0.342

4. DISCUSSION / CONCLUSION

Revisiting initial hypotheses

The ability of QdF models to represent both rural and urban flood-peak distributions is conformed at the experimental site and has been demonstrated in many other periurban sub-basins (Braud et al., 2011). Then H1hypothesis is confirmed.

Full concomitancy between urban and rural flood-peaks (H2 hypothesis) for small basins is not fully confirmed for the experimental basin of 2.7 km2 with a 3% of impervious surface connected to the combined sewer system. Urbanization in that case mainly develops in the downstream part of the sub-basins. The lack of concomitancy confirms that urban floods can evacuate partly before rural flood peaks arrive next to the CSO outlet. It is also known that concomitancy between urban and rural floods increases when urbanization develops upstream a small catchment rather than in its downstream part. Then only 20% of urban flood peaks are considering in this study using observed data from the experimental sub-basin. This can be considered a low rate of urban flood contribution observing that in the set of 45 sub-basins the average value of % urban varies from 7% to 15% between 2008 to 2030 and that 19 over 45 sub-basins are less than 1 km2 in area. For these reasons the presented BFD ratios could be underestimated overall. This choice can impact the detection of ratio reduction that would result from the runoff control strategy. It seems necessary in future studies to consider the urban development location in a sub-basin to get more precise results on this issue.

From Fig.3a it is observed there are 4 incised sub-basins with %urban ranging from 0 to 0.2 % and for which BFD ratios are in the lower range for this group (from 1.2 to 1.42). These near fully rural basins are very sensitive to incision which can be induced in that case by a land use change like natural reforestation. This occurs in periurban areas where farmland activity is progressively abandoned to the benefit of land speculation for future urban development. The consequence over time is a lack of sediment input to stream bed which modifies the historical sediment balance. This is because forest vegetation better trap fine sediment than cultivated lands. The result is incision in response to a lack of sediment input but not in reason of flood regime change. This sub-group of 'rural incised stream bed' can be considered apart from the other to propose a ratio over which urban% can induce an incision process. The median BFD ratio value for incised stream is of 1.60 with n=16. This value also figures the limit of sub-basins with %urban over 5%. It is then considered as a reference ratio from which incision process can start in the Yzeron basin.

Given the 1.6 ratio limit it is possible to estimate the number of additional sub-basins that would develop incision by 2030. From Fig.4 there are 3 sub-basins over this limit in the no incision group (N) on 2008 and 13 on 2030. Given the varying sensitivity of stream-beds to incision it is not possible to say they will all start to get incised but the probability is of 0.45 (13/29) which is not negligible at least. Add to this it must be considering that ratios calculated for the 5 sub-basins that are over the 1.6 ratio limit without exhibiting incision on 2008 (N group) will increase on average by 8% on 2030 which is enough sensitive and would impulse incision. Also the evolution ratio of 7% for the 4 highly sensitive sub-basins (rural incision sub-group) with urban development by 2030 will have for sure an impact.

The lack of efficiency to control incision on 2030 with new urban runoff management – here simulated using a constant flow rate imposed by regulation – shows that magnitude of frequent flood-peaks is not so affected. This is because on one side the domestic flow rate increases with population increase inducing more frequent CSOs in the inherited 2008 sewer network system. On the other side retention structures build to limit runoff flow rate have the effect to sustain base flow in streams, finally increasing the rural contribution to QdF-rural. Then urban runoff disconnexion from existing 2008 combined sewer system should be considered in new scenarios to address both incision reduction and base flow amplification in favor of aquatic ecosystems.

Considering the experimental design based on a representative set of sub-basins showing diversity in their response to urban storm-flows and also diversity in their urban future developments we can expect to generalize the method to the whole Yzeron basin area as to get a basin scale assessment.

The spatial variability of stream bed susceptibility to incision should be taken into consideration to condition the location of on-site rain water retention for future urban developments. This "ecosystem prevention" criteria effect is confronted to the global efficiency in flood hazard reduction.

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