OnLine Journal of Earth Sciences 1 (4): 194-198, 2007
ISSN: 1991-7708

Influence of the Urbanization on the Risk of Flooding by Runoff

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Abstract: The urbanization is a recent enough phenomenon so much in the industrialized countries that in the developing countries. One of the most visible consequences of the urbanization is the impermeabilisation of soils, which influences considerably on the features of the hydrological response of the watershed and was often bets forward to explain the urban flooding by runoff. In this study, we used like model of simulation, the non-distributed one of linear reservoir, to determine the influence of the urbanization on hydrological response of the watershed. The obtained results show that in case of the urbanization, the lag time of the considered watershed is a lot shorter and also the peak flow increases considerably.

Key words: Urbanization, urban hydrology, runoff modelling, linear reservoir models

INTRODUCTION

The importance of the flooding by runoff is bound to the morphology of the watershed and to the climatic conditions. The human activity, as the urbanization, constitutes one of the factors aggravating the risk of flooding (Caber and Balades, 2004). The first consequence of the urbanization is the impermeabilisation of soils that causes a reduction of the infiltration in these last and contributes to an increase of the streamed volumes. Under the effect of the impermeabilisation, some watersheds saw their lag time divided by an active factor of five to fifteen (Desbordes, 1989). In the developing countries, as Algeria, the growth of the industry involved a real urban demographic explosion. The emergency to build often limited the reflection on the consequences of the urbanization on the water cycle in urban environment. At the present time, these consequences become obvious and with them their succession of nuisances of all orders: Permanent dysfunctions of the urban sewer systems and frequent floodings (Benabdesselam, 2007). To be able to act better on the risk of floodings and to manage it, the most efficient mean is the previous simulation of the effect of the urbanization on the hydrological response of the watershed to urbanize during his urban planning process. The dynamic methods, used in urban hydrology, permit to simulate the water cycle since rain until the flow in the outlet of the watershed, that is to say, to get a representation of the hydrograph. The dynamic modelling includes several steps (Chocat, 1990, 1997) modelling of the rain whose model represents the fundamental entry to the runoff models and to the runoff modelling.

MATERIALS AND METHODS

Modelling of the runoff: The runoff can be defined as the hydrological response of a watershed to a shower and represented by the evolution in the time of the flow on a given time interval (runoff hydrograph) during this shower. This response corresponds to an interaction between the morphological features, the nature of the soil and the occupation of the soils of the watershed. To value the runoff hydrograph of the watershed, we had resort to a conceptual storage model (reservoir model). The latter considers the watershed like a complex system of reservoirs achieving a transfer of flux. The more used reservoir model in urban hydrology is the linear reservoir model, which represents the transformation of a rainfall excess hydrograph in hydrograph in the outlet (Chocat, 1997).

The linear reservoir model combines the equation of continuity:

$$\frac{dVs}{dt} = Qe(t) - Qs(t) \quad (1)$$

with a storage equationlinearly joining the stocked volume to the retiring flow:

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$$Vs(t) = KQs(t) \quad (2)$$

Where, K is the parameter of the model, homogeneous to a time and named lag time (s); Qe(t) represents the entering flow or the flow of rainfall excess (m3/s); Qs(t) is the flow at the exit (m3/s); Vs(t) gives the instantaneous stocked volume in the watershed (m3/s).

For a stationary linear system, which is not spatially distributed, the linear reservoir model expresses itself directly from the Eq. 1 and 2 in only one differential equation:

$$K\frac{dQs}{dt} = Qe(t) - Qs(t) \quad (3)$$

The instantaneous unit hydrograph of this system is given by the following relation (Deutsch *et al.*, 1989; Rodriguez, 1999):

$$U(t) = \frac{1}{K} E\, e^{-t/K} \quad (4)$$

The parameter K will be determined by the relation proposed by Desbordes (1987):

$$K = 5.07\, A^{0.18} (1 + IMP)^{-1.9}\, I^{-0.36} L^{0.15} Hp^{-0.07} Dp^{0.21} \quad (5)$$

Where,

- A : Surface of the watershed (hectares).
- Dp : Duration of the period of critical rain of the basin (min).
- Hp : Rain height during this length (mm).
- I : Slope of the longest course (%).
- IMP : Imperviousness coefficient (%).
- L : Length of the longest water travel (m).

For the little urbanized or rural watershed, we opted for the model of two linear reservoirs in series with the same parameter K (Chocat, 1990). The instantaneous unit hydrograph, corresponding to this type of model, answers to:

$$U(t) = \frac{1}{K}\left(\frac{t}{K}\right) e^{-t/K} \quad (6)$$

Where:

$$K = c\, L \left(\frac{A}{I}\right)^{0.5} \quad 0.6 = c = 1.8$$

The runoff models, developed above, treat the transformation of the only rainfall excess in flow. Sometimes these models are called as transfer function. But their implementation requires a previous modelling of the losses which achieves the transformation of the gross rainfall into the rainfall excess. This last is called production function. To this subject, one will note that the rainfall excess doesn't cover any observable physical reality, it represents the gross rainfall fraction, before this last arrives to soil and that will server only to the food of the runoff in the outlet of the considered receiving surface.

Modelling of the rain

Design storm model: The fundamental entry of the urban runoff models is the design storm or the synthetic hyetograph. The design storm is a fictional rain event. Currently, in the most countries, the used design storms are characterized by neighboring shape hyetographs. These last are constituted of a period of relatively long rain of sustained intensity, inside which comes to fit a shorter episode, characterized by a very strong intensity which return period is associated to the design storm. The met shapes are variable: Triangular, fitting of rectangles (design storm of Chicago type), of trapezes (Bemmo and Chocat, 1993), etc. The design storm model that we chose is a simplification of Desbordes's model (STU, 1986): Design storm of double symmetrical triangle form or Chocat-Thibault's model (Chocat, 1997). The interest of this model, it is that the features of the design storm (total rain duration, length of the intense period, precipitate heights), can be obtained from the features of the watershed and from the local curves IDF (intensity-length-frequency). For the curves in question, we propose the methodology of construction.

Construction of the IDF curves: The obtaining of the IDF curves requires the transformation of the raw values of the precipitations in a set of annual maximal values on different lengths (τ = 5,10min,..), then the adapted adjustment to the data of the obtained set (Lam *et al.*, 2004). It has been determined that the shapes of empiric frequential curves of the heights of the maximal precipitations for the different lengths $H\tau = H\tau(F)$ and of the maximal daily precipitations Hj(F) for the same period of observation are identical and. Following this definition, we propose to present the report of the values $\varphi(\tau) = H\tau(F)/Hj(F)$ corresponding to a given frequency (F), under the following exponential shape:

$$\varphi(t, T) = a_0(T) * t^{n(T)} \quad (7)$$

Where, a_0 and n are the adjustment parameters; T is the return period (T=1/F) in years; t is the duration.

In this case, the report φ (t,T)/t = i_0 (t, T) will present a reduction curve:

$$I_0 (t, T) = a_0 (T) * t^{-b(T)} \quad (8)$$

with i_0 (t, T) as the mean maximal relative intensity ($\frac{mm}{mm*min}$).

The mathematical expression of the families of IDF curves deduced from the product of the Eq. 8 and the daily precipitations Hj (T). It is of the following type:

$$I (t, T) = a (T) * t^{-b (T)} \quad (9)$$

Where, i (t, T) is the mean maximalintensity on the duration tfor a returnperiod T; a (T) = a_0 (T) * Hj (T).

This methodology permits to determine the IDF curves for the same climatic zones that the considered measure station, for this it is sufficient to know the frequential curve of the daily precipitations of the zones in question.

Modelling of the runofflosses: The losses and the runoff are enough difficult phenomena to dissociate. They occur at the same time and are often dependent. To calculate the hydrograph in the outlet of the watershed, it is of use to make use of two models:

- The first model, production model or model of the losses, transforms the gross rainfall into rainfall excess, that participates effectively in the runoff.
- The second model, model of transfer, transforms the rainfall excess in hydrograph in the outlet of the watershed.

For an urbanized watershed of which the imperviousness coefficient is superior to 20 %, when one uses the linear reservoir model as transfer model, what is of our case, the runoff losses are represented by the imperviousness coefficient IMP (Deutsch, 1989). It implies that the initial losses are negligible and that one doesn't take in account, at resulting hydrograph level, the effect of the permeable surfaces. On the weakly urbanized surfaces, the losses and runoff phenomena result from a set of transformations bound to the features of the soil and to the climatic conditions. For a rural watershed, these notions are replaced by the one of the mean blade (variable in the time, which one can decompose in initial losses and continuous losses). The continuous losses that are provoked by the phenomenon of infiltration concern only the permeable surfaces and are more important than the initial losses (storage in the depressions). To describe the losses due to the infiltration of the rural watershed, we chose the most current model, the Horton model (Bennis, 2003):

$$f (t) = fc + (fo - fc) e^{-kt} \quad (10)$$

Where, f (t) is the limit speed of potential infiltration at time t (mm / h); fc is thelimit speed of infiltration (mm / h); fo is the initial speed of infiltration at time 0 (mm / h); k is thefactor depending of the soil-vegetation complex.

For the rural watershed, the transformation of the gross rainfall hyetograph in the rainfall excess hyetograph is defined as follows:

$$in (t) = ib (t) - f (t) \quad (11)$$

with in(t) as the rainfall excesshyetograph and ib(t) as the design storm hyetograph.

RESULTS AND DISCUSSION

The zone of study is located in the South part of the city of Annaba (Algeria) and is included in the development and urbanism plan of the region, like zone to urbanize. Actually, the considered watershed is little urbanized (rural watershed) and covers a surface of 278 ha. The talweg length is of 1800 m and the mean slope is equal to 6%. The particularity of this watershed is to be crossed by a road, which is perpendicular to the talweg. This road has an evacuation work of the storm waters whose hydraulic capacity is equal to 8.8m3/s.

To construct the hyetograph of the design storm, we conducted the establishment of the IDF curves from the sets of pluviometrical data given by the meteorological station situated at 2 km of the survey zone for a period of observation of 17 years. The sample to analyze was constituted of the annual maximal values of the precipitations corresponding to the different steps of times (15, 30, 60 min) and of the daily precipitations. These sets of data have been adjusted to the law of Gumbel, which is satisfactory for the short durations (Bourrier, 1997; Meylan and Musy, 1999). The values of the adjustment parameters a_0(T) and n (T) as well as of the parameters a (T) and b (T) are carried in the Table 1.

The calculations of the quadratic errors for the different return periods showed that their values don't exceed 8%. On the other hand, the relative errors (ε) between the empirical values and the theoretical values of the rainfall intensity for the different steps of time (ε (τ, T)) exceed, sometimes, the 10%. The relative maximal error (εmax = 14%) has been observed for the time interval τ = 180 min (T = 100 years). To construct the design storm and to define the parameters of the intense period, we used the IDF curve corresponding to the return period equal to 50 years. The hyetograph of the design storm is represented in the Fig. 1. This hyetograph is

Table 1: Adjustment parameters

Return periods	Parameters a_o	n	a	b
10 years	4.85	0.33	452.36	0.67
20 years	4.58	0.34	493.66	0.66
50 years	4.29	0.35	555.24	0.65
100 years	4.16	0.36	601.83	0.64

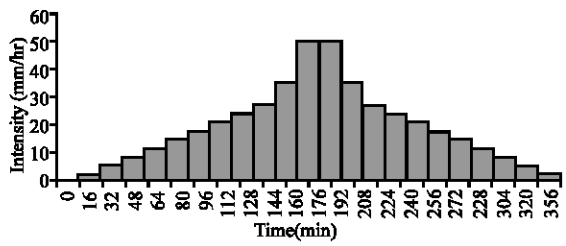

Fig. 1: Design strom (double symmetrical triangle)

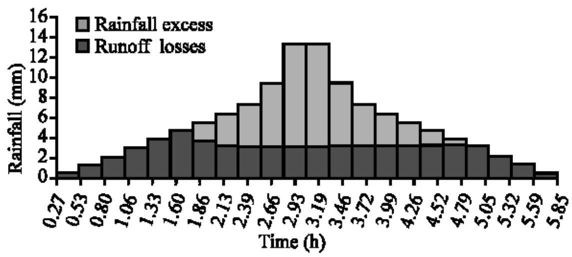

Fig. 2: Hyetograph of rainfall excess

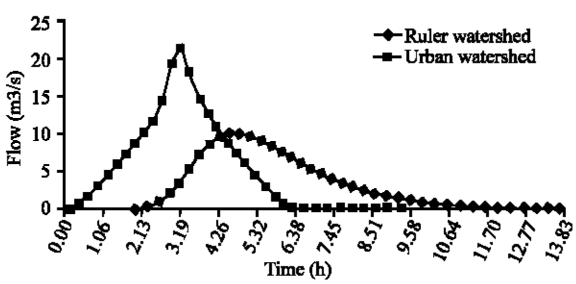

Fig. 3: Hydrographs

defined like entry of the runoff model of the urban watershed of which the degree of impermiabilisation is expressed by the imperviousness coefficient IMP = 60%.

The application of the Eq. 10 and 11 permitted us to construct the hyetograph of the rainfall excess, that is the entry in the runoff modelof therural watershed (Fig. 2).

The hydrological responses of the urban watershed and the rural watershed to the 50 years return period rainfall are represented by the hydrographs in the outlet (Fig. 3). The obtained results express the effect of the urbanization on the hydrological response of the watershed. We observe that the urbanized watershed distinguishes itself by elevated flows, by a short lag time and by a very pronounced flood peak. In the local context, since the capacity of the evacuation work of the rain waters is insufficient, one considers the downstream of the basin as flooded.

CONCLUSION

The urbanization is the one of the factors aggravating the flood risk by urban runoff. To act efficiently upon the risk, it is to take in consideration the state of the basin. Simulations to become the runoff waters, for the episodes of decennial, centennial occurrence or even exceptional, must be done in the development stage of the land use plan. This approach will permit to develop a strategy of reduction of the runoff and the pluvial waters concentration. The runoff reduction can be achieved by reduction of the impervious surfaces or by technical solutions. However, it is necessary to recall that the technical responses don't suppress flood risk, but that they permit to manage it.

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