Design storms and parameters for water quality control of urban runoff

Pluies et paramètres de conception pour le contrôle qualitatif du ruissellement urbain

Gilles Rivard

Lasalle | NHC inc., 9620, Saint-Patrick, Montréal, Canada
(grivard@lasallenhc.com)

RÉSUMÉ

Les critères de contrôle qualitatif pour le ruissellement urbain sont maintenant intégrés dans plusieurs guides de gestion des eaux pluviales. En reconnaissant qu'il n'est pas nécessaire de capter et de traiter les événements très importants, l'objectif qui est le plus souvent retenu est basé sur une analyse des précipitations et de leur distribution, de façon à pouvoir établir les quantités de pluie à utiliser pour la conception. L'hypothèse de base est qu'en captant le ruissellement généré par une quantité donnée de précipitation (typiquement entre percentiles 85^{e} et 95^{e}), une portion importante du ruissellement annuel sera traité.
Les critères existants pour le contrôle qualitatif utilisés dans différentes régions de l'Amérique du Nord sont tout d'abord abordés, en distinguant les pratiques conçues avec un critère impliquant un volume de ruissellement et celles conçues avec un débit de conception. Les simulations du ruissellement avec une base de données de 14 ans de précipitations avec un pas de temps de 5 minutes ont été utilisées pour évaluer les différents critères inclus au Guide de gestion des eaux pluviales pour la Province de Québec (Canada) (MDDELCC, 2011). Les résultats obtenus avec les simulations en continu et des analyses complémentaires sur la pluviométrie ont permis de formuler des recommandations spécifiques pour définir adéquatement les paramètres de conception pour le contrôle qualitatif.

ABSTRACT

Quality control criteria for urban runoff are now part of many guidelines for stormwater management. Recognizing that it is not necessary to capture and treat the extreme runoff events, the target most commonly defined in these guidelines is based on an analysis of the precipitation with a rainfall distribution plot to determine a rainfall quantity to be used for design. The basic assumption is that by capturing the runoff generated by a given quantity of precipitation (between 85th to 95th percentile usually), a significant part of the annual runoff will be treated.
Existing design criteria for water quality control as used in different North American regions are first given, distinguishing between Source Control Measures (SCM) designed with a volume-based criteria or a rate-based criteria. Runoff simulations with a database of 14 years of rainfall at 5 minutes interval is thereafter used to assess the different criteria as given in the Stormwater Management Manual for the Province of Quebec (Canada) (MDDEP/MAMROT, 2011). The results obtained from the continuous simulations and further analyses of the rainfall data finally provide a basis for specific recommendations to properly define design storm distribution and parameters for water quality control.

KEYWORDS

Design storms, Water quality control, Source control measures, Stormwater management criteria, Low Impact Development

1 INTRODUCTION

The control of stormwater runoff quality is now included in many North American jurisdictions as one of a group of practices to minimize the impacts of urbanization on receiving watercourses. Defining appropriate design criteria for quality control could be especially complex for a number of reasons and, as the detailed environmental impacts of urban stormwater runoff on receiving waters are rarely assessed in detail for each project, many criteria rely on an analysis of rainfall historical series to determine design values that would ensure treatment of a given portion of the average annual runoff. The basic goal is therefore to treat from 80 to 95 % of the average annual runoff, based more on political or economic considerations than a detailed environmental analysis as the benefits to treat large runoff events are not usually balanced with the much larger facilities that are then necessary.

Practically, after a given treatment percentage of average annual runoff is accepted as a basic requirement for runoff quality control, design parameters have to be determined so that the treatment target could be met. Logically, the best approach would be to use detailed continuous modeling with rainfall data at a sufficiently small time steps so that average runoff parameters could be determined, thereby enabling to assess the design against the basic requirement. Unfortunately, due to the non-availability of this type of data or to time or budget constraints, this is rarely done in practice and simplified design criteria have therefore been derived. One of the fundamental problems to specify adequate design criteria is that some Source Control Measures (SCM) are designed as rate based treatment systems and others as volume based treatment systems; different design criteria should therefore, in principle, be derived for each type of facility. The situations in practice are even more complex as the different types of SCM are often used in series within a treatment train.

This paper describes approaches to derive and validate design storm and design rainfall data that could be used for runoff quality control. A brief literature review of available design criteria for runoff quality control, completed as part of the analyses for the Stormwater Management Manual for the Province of Quebec (Canada) (MDDELCC, 2011), is first given. The existing criteria are then applied to climate conditions prevailing in the Province of Quebec and compared with modeling results obtained for typical applications. This provides the basis for specific recommendations to define appropriate design storms and parameters for quality control.

2 BACKGROUND AND APPROACH

The objectives for runoff quality control have been based in recent years on an analysis of the distribution of rainfall quantities, with a basic assumption that most of the runoff is produced by relatively small storms. Such an analysis is given for the Dorval Airport meteorological station in Montreal (Canada) in Figure 1, with the rainfall events being determined with a minimum interevent of 6 hours and a minimum rainfall quantity of 1 mm.

As shown on the plot, the rarer events used for conveyance and flooding represent a very small portion of the total events whereas 90 % of the storm events have a quantity of 22 mm or less. The same type of analysis for other stations in the Province of Quebec have given similar results, with the rainfall quantities for the 90 % threshold varying from 22 to 26 mm. A rainfall quantity of 25 mm have therefore been recommended as an average for quality control (MDDEP/MAMROT, 2011). Another way to look at this for a given year is shown in Figure 2 and, once again, it could be seen that most of the events have a quantity less than 25 mm. It therefore appears to make sense to control the runoff generated by events less than 25 mm as most of the annual runoff would thereby be managed.

Different design storms have been proposed in the literature to model frequent rainfall events for SCM design. The New Jersey stormwater manual (NJDEP, 2004) in the USA recommends using a 2 h mass curve for a 31.8 mm quantity (1.25 in.). Seattle and Portland, two cities on the western part of the USA, have also developed design storms for quality control. Both have determined design storms of different durations and emphasized the fact that design storms should take into account the main criteria to be used for design: for some practices like detention basins, bioretention or infiltration systems, the design parameter is the runoff volume whereas for others, like hydrodynamic separators or swales, the design parameter is the discharge rate. The Province of Ontario (Canada) (MOE, 2003) recommends on the other hand a 25 mm Chicago-type storm, with 4 h and 2 h durations (as based in the distribution defined by Keifer and Chu, 1957) and the City of Calgary (Alberta, Canada) uses a water quality event of 15 mm, with durations of 1 hour or 24 hours. Most of the other stormwater manuals give only a rainfall quantity for a specified percentile, with no indication for a specific design storm. During the preparation of the Quebec's stormwater manual, this was perceived as incomplete as it was recognized that some practices like swales or hydrodynamic separators have to be designed with flow rates.

Some guiding principles were used to come up with design storm and parameters for water quality control: the design data should be simple to derive and easy to use for small projects without extensive continuous modelling; it should provide design information on runoff volumes and discharge rates; use of the rational method and modelling with a design storm should give similar results.

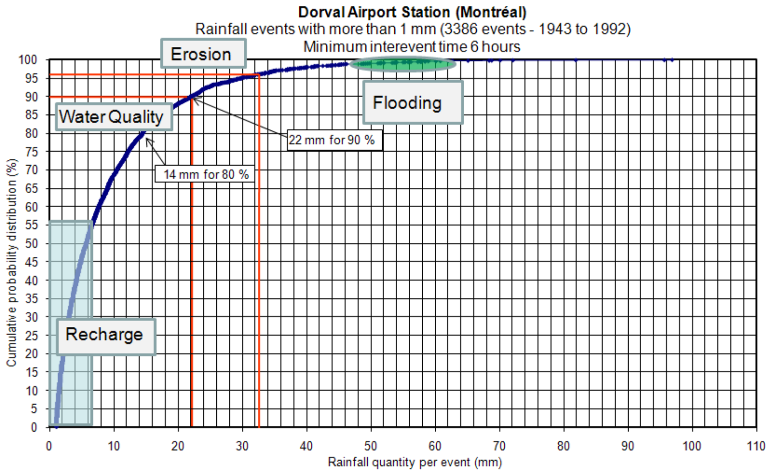

Figure 1. Analysis of hourly rainfall events at Dorval airport, Montreal (Canada), for the period 1943–1992.

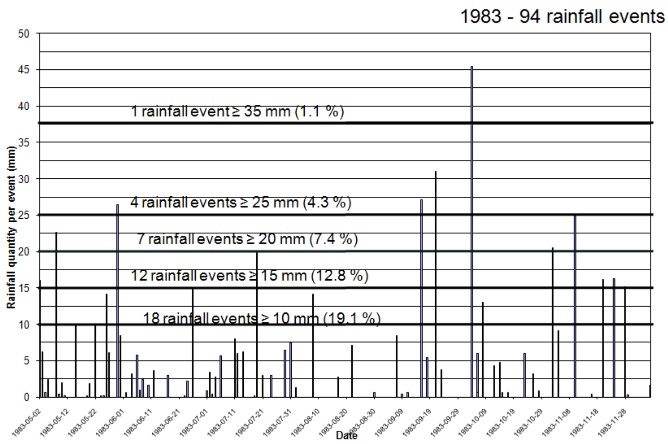

Figure 2. Rainfall events for 1983 (May–November)—Dorval airport, Montréal (Canada).

3 RESULTS AND DISCUSSION

As the time distribution defined by Keifer and Chu (1957) for the region of Chicago is still largely in use for stormwater design in Canada, it was retained as the time distribution for the water quality event. The total rainfall quantity in the hyetograph, as defined by the analysis shown graphically in Figure 1, was between 22 and 26 mm, with an average value of 25 mm for the Province of Quebec. Different durations were thereafter tested (between 2 and 24 hours) and the results (both runoff and peak discharges) were then compared to the continuous modelling using the rainfall data. A duration of 6 hours provided the best compromise after the comparison with the simulation results. The rainfall intensity, which is the most important parameter for the peak discharge, is directly related to the time step selected when the Chicago-type time distribution is used. In order to give results similar to the simulations with historical time series, a time step of 10 minutes had to be selected. Moreover, as the peak discharges were still too high when compared with the simulation results for typical applications, the peak rainfall intensity had to correspond to a 15 minutes interval, with the quantities being redistributed to the 2 intervals on each side of the peak. The design storm finally recommended in the

Quebec's guidelines is shown in Figure 3.

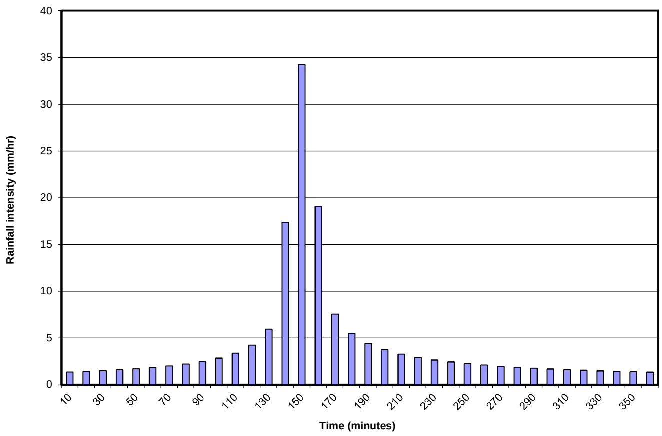

Figure 3. Design storm recommended for quality control, Quebec's Guide for stormwater management (MDDELCC, 2011).

In actual design situations, if the parameter is the water quality volume, the calculations are based on a rainfall quantity (22 to 26 mm) multiplied by a runoff coefficient and an area to obtain the water quality volume to be treated. An alternative with modeling would be to use the hyetograph on Figure 3, which could also be used to determine the water quality discharge. For small projects when the rational method is appropriate, the discharge could be determined with a specific Intensity-Duration-Frequency (IDF) curve developed for a 1 in 6 months return period. This is similar to the approach proposed in recent reference documents (WEF/ASCE, 2012).

4 CONCLUSION

Design data for water quality control for urban runoff is site-specific but it should be determined with a recognition that some practices are designed with a runoff volume to be treated whereas others are dimensioned with discharge rates. Although they have to be tested and verified against long-term continuous modeling to ensure that they provide adequate results, the design parameters should ideally be simple to use for any type of projects.

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