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Urban Drainage and Climate Change: Toward the Best Management Practices

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Abstract—It has become now clear that Climate Change (CC) is a reality across the globe. Regarding urban drainage (UD) and the CC, some studies have concluded that the risk of flooding in urban areas would increase in the future at least 2 times [1]. This will have a significant impact on maintaining the service level of the urban drainage systems.

In this context, an approach based on source control, is often less privileged in the traditional approach to design drainage systems, it can become a key element in implementing new approaches with control volume and the range of rainfall events, especially for frequent events [2] [3]. The integration of source control in urban areas also underlies a redefinition of design concepts across urban development [4].

The term "Best Management Practices" (BMPs) or more recently LID (Low Impact Development) presents new more holistic trends for storm water management. The objective of this approach is to encourage infiltration and locally control the flow rates and volumes for frequent events. Subsequently, these trends have profound implications for the planning, design, and financial and operational aspects of drainage networks [5].

In a context of CC and considering the percentage increase of flows and runoff volumes that can be expected, the question that now arises is what extent and how effectively the different types of techniques can be used.

This article aims to:

1) Provide an overview on the technical approach related to the Best Management Practices;

2) Present innovative solutions; tested in some developed countries; for an improvement of urban drainage system services to reflect the new climate expected in the coming decades.

3) assess the effectiveness of such measures in order to offset the additional risks posed by CC in flood and discharge of rainwater;

4) Present the foreseeable gain following the introduction of alternative techniques as adaptation measures to CC.

Index Terms—Adaptation, Best Practices, Climate Change, Stormwater Management, Urban Drainage.

1 Introduction

IN urban areas, the management of the water cycle is based on the establishment of a number of infrastructures for the drainage of rainwater, which represents a considerable achievement for our societies [6]. The recent awareness of the rapid deterioration of urban drainage infrastructures has also highlighted the risks posed by climate and weather hazards on the functioning and sustainability of urban drainage system. Hence the importance of considering the CC with its expected impact on the water cycle, which should result, in some areas, significant changes in rainfall and a greater likelihood of occurrence of intense rainfall events [7].

More globally the measures would help to face the anticipated effects of CC on urban drainage system are essentially twofold: the first approach is to revise the design criteria that are basically attached to the return periods and rainfall data by means of: 1) the revision of the return period of the events used for the design of urban drainage system [7] [8], 2) or to consider, case by case, the percentages of increase of the rainfall following a climate modeling [5].

The second approach based on a more holistic vision of urban drainage that will be covered in this article. This approach is of broader application and may be necessary to help offset hydrological changes associated with CC through a transformation of urban drainage infrastructures of what they were (ie a pipe network for fast and efficient rainwater collection) to a more "green" system with landscaping formed ponds and wetlands integrated into the urban water cycle [5][6][7][9].

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2 City And CC: Hydrological Cycle And Urban Drainage

CC is likely to cause change and natural hazards that may affect our society negatively [6] [7]. This vulnerability depends on multiple factors, including urban planning, local economic activities, and the existence of protective infrastructure. The most significant specificity of the impacts in urban areas is their interdependence. Because cities are highly integrated systems and highly dependent on networks (water, electricity, transport, communication), so the impacts in different sectors interact and must be considered in a holistic way [9]. A major risk is that of flooding due to runoff when the rainwater drainage networks are overwhelmed by the intensity of precipitation. This risk is particularly important because some climate projections show an increase in violent events of precipitation [10] [11] [12]. In addition, it should be added the role of impervious urban area, which reduces the direct absorption capacity of the soil and thus increases the runoff that drainage systems must be able to absorb. This risk is particularly high in areas where produce intense events of precipitation [7] [9].

2.1Urbanization and the hydrological cycle

Urbanization in a watershed can produce significant changes in the natural water cycle. The replacement of permeable soils that exist in the natural state by impermeable areas such as roads, increases of the quantity of runoff and the degradation of receiving environment [9]. Overall, urbanization causes a significant alteration of the amount of infiltrated water and also the part of precipitation that can evaporate, which substantially influences not only the peak rate that are generated but also the volumes of runoff [1] [5] [7]. This impact on the hydrological regime is also not uniform in terms of return periods of considered events. Indeed, several studies have shown that the effects of urbanization on the runoff rates are proportionately larger for frequent events for the exceptional events. For example, Hollis (1975) observed for a basin with an impermeable percentage of 30% that the recurrence of 1 in 100 years increased by a factor of 1.5, while those for a recurrence of 1 in 2 years increased by factors varying from 3.3 to 10.6 respectively [13].
Moreover, as more land becomes urbanized, there is an increase in runoff for frequent rain (eg less than a frequency of 1 in 2 years) and, consequently, to an increase in the frequency of occurrence of peak rate in the urban drainage system [9]. Hollis (1975) and several other researchers reported that it was not uncommon for an event with a return period of 1 in 10 years becomes, with increased urbanization, a more frequent event, with such a return period of 1 in 2 years [13]. Another important feature for urbanized watershed is producing runoff even for relatively small rainfall events [9].

2.2 Impacts of CC on urban drainage:

In a context of CC, Conditions the urban drainage system (DU) may change given the spatiotemporal changes expected in precipitation. An intensification of extreme events will result in a higher flood risk in urban areas and deterioration of the quality of receiving environments [5]. Several studies have established, at least preliminarily, the range of increase in precipitation that could occur in the near future. As in precipitation increases that were modeled future climate using a regional climate model and based on certain assumptions, the increase in flows and runoff volumes resulting from these changes could thus be established. Mailhot et al (2007) found that the quantities of precipitation could increase by 2040 from 4 to about 21%, depending on the return period and duration of the precipitation [5].

For a duration of 2 hours, which would be a representative period for storms that are most critical in urban areas, the results of the study Mailhot et al (2007) provide a range of increase from 13 to 21% [5]. It will be noted, as shown by the results presented in the detailed study of Mailhot et al., (2007), that the impact of the increase of precipitation on the flows and volumes of runoff is not linear. Thus, for areas with land used for residential building, increases in flows rates and runoff volumes obtained by modeling are larger than those for precipitation [5].
Moreover, regardless of the method used to evaluate future climate in rainfall intensities, all impact studies reported in the literature using these intensities as input to a model of hydrologic / hydraulic simulation of urban drainage networks to estimate the impact of these increases on network flows and runoff volumes [7]. it should be noted, in addition to expected variations in rainfall intensities, some studies also consider the potential growth of urban areas in the coming decades (growth areas connected to the network and increase the percentage of impervious drained areas [1]).

3 UD & CC: Possible Adaptation Measures

Since it appears that the increase in rates and volumes of runoff due to CC are relatively large, so it is necessary in this context that certain measures that can mitigate these changes [3][4]. These measures can take many forms and can be considered as part of a control function as illustrated in Figure 1, with interventions that may be closer to the source and others further down the networks [9].

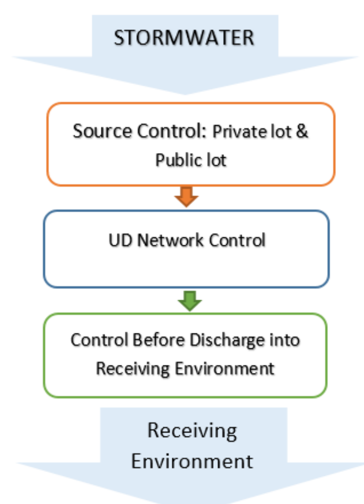

Fig. 1. Runoff control mechanisms chain (adapted from GGEP [9]).

These measures must also be defined taking into account a number of principles for the management of stormwater in urban areas [2][3][9]:

- Traditionally, control of stormwater is often less for residential areas (especially when there is no hydraulic under-capacity of existing networks downstream) where it is

now more common for large paved areas that are associated with commercial and industrial sectors. As the increases, can be anticipated for residential areas are substantial, we will include more controls to be able to offset these increases [4]. A redefinition of urban planning involving development concepts, landscaping and design engineer of drainage systems will have to be better disseminated in practice. In this context, the source controls are no longer an alternative technique but should be a basic approach for new networks to compensate for the longer-term effects of CC, even when there is no network overload problem observed for current conditions [9];
- Frequent flows (return period of 2 years or slightly less) are typically associated with erosion in the rivers as these rates are known to contribute substantially to the definition of the hydraulic section of rivers [2]. The increase in these rates can therefore result in a significant increase in erosion and degradation of ecosystems, especially as for residential areas, runoff flow can increase by 33% [9];
- On the other hand, the types of measures that can be considered will necessarily differ depending on the case with an existing network or a planned network. In the case of a planned network, it is obviously easier to adequately plan networks with controls that are needed so that increasing flow and volumes can be compensated [4]. Most of the measures included in the diagram in Figure 1 can be applied alone or in combination, keeping in mind that it is often cheaper to control the flow and volumes as possible upstream, near the source [4].

More generally, the measures would be useful to adapting UD to anticipated effects of CC are essentially twofold: 1) to revise design criteria and 2) to modify the ways to do for design and implementation of networks, incorporating more Best Management Practices (BMPs) to control stormwater at source and with a more comprehensive approach involving better integration of green spaces in urban areas [14].

Regarding the design criteria, they are fundamentally attached to the selected return periods and rainfall data. Two approaches can be selected as adaptation measures [5]:

- If we continue to use current information from the IDF (Intensity-Duration-Frequency) curves can be used for designing a longer return period. For example, the return period that is most often used for network design using a traditional approach is 5 years. To maintain this level of service, it is therefore appropriate to raise this return period to 10 years, if current rainfall data are used for design. So, if you want to keep a level of service from 1 in 5 years to a situation envisaged in 50 years (so below the useful life of networks) could take (based on current data) return period 10 years to the design. Similarly, the retention volumes expected for different return periods should be increased.
- Another approach would be to consider, case by case, rain percentage increases that have been defined by the climate modeling.

The revision of the design criteria can more easily be able to adapt adequately in the case of existing networks as the behavior of these networks often depends on network portions further upstream and rehabilitation costs can quickly become prohibitive [5][9]. A more comprehensive approach, using a more holistic vision of urban drainage, wider application, in this case may be required to help offset hydrological changes associated with CC. The following sections will discuss in more detail of the approach based on Best Management Practices (BMPs) and the various techniques that can be used in urban drainage system.

4 BMPs Challenge In Urban Drainage

Several studies recommend a change in paradigm in the design of drainage systems and describe more holistic approaches that minimize the impacts of CC and urban development [2] [5] [9] [15] [16]. The question now, in the context of CC and considering the percentage increase of flows and runoff volumes that can be expected is to what extent and how effectively the different types of control can be used. Two aspects need to be considered here. First, we must establish the extent of the benefits that can bring a particular measure and assess this measure, alone or in combination with others, this may help to offset the increases are considered [5]. Second, we must assess the feasibility of using different techniques or not to a specific case, taking into account the specificities and constraints of the study area [15]. Thus, the designer will usually have less flexibility in existing networks in densely urbanized region that for sectors with a projected land use low density [5]. The lack of space and the physical layout constraints make such more difficult the use of certain surface steps to the center of major cities [9]. Using the nomenclature given to the control system shown in Figure 1, the following section present the source control techniques as category of BMPs used in UD:

4.1 Source Control Techniques

Several types of source control can be considered appropriate for different types of urban areas. For commercial, industrial and institutional sectors, retention of local areas can easily be arranged, either on the parking areas or sub parking (Figure.2). For residential areas, controls may be made on private lots or on public properties (ie the streets):

- On private lots, the most interesting measures are adding absorbent soil or using infiltration facilities (e.g. bioretention areas) that are designed to retain runoff and provide time for it to infiltrate [15]. This type of control will help to eliminate the direct runoff by maintaining the capacity of infiltration and evaporation in impervious surfaces (Figure.2, 3 and 4) on development parcels (rooftops, driveways, parking lots) and roads (paved roadways and sidewalks).
- On the streets, a redevelopment like those shown in Figures 5 will allow a certain level of control for the more frequent rains. For areas with streets with low longitudinal slopes, we can also use the volumes available at low points with sumps to control which may limit the entry of water to the network [14]. Walesh (1999) used this approach, by adding berms on the pavement, so as to create larger storage basins [17]. Figures 5 and 6 illustrate these approaches. However, in this type of application, it is necessary to make field validations to ensure that problems

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will not be created (the slope, lowered land, etc.) [5]. Furthermore, the analyzes carried out in North America (Canada) [15] help provide answers about the level of benefits that can be associated with certain types of source control on the lots. The next section analyzes benefits where control measures are combined.

Fig. 2. Example of planning for parking areas in the city of Portland USA [9].

Fig. 3. Example of development of a residential street in the city of Seattle USA with bioretention area [9].

Fig. 4. Example of development of a residential street in the city of Seattle USA with bioretention area [9].

4.2 Combined effects of several BMPs measures

Several case studies have shown the potential benefits to an urbanized area where control measures are combined. For example, in Canada, simulations for a cloudburst (100 years' short

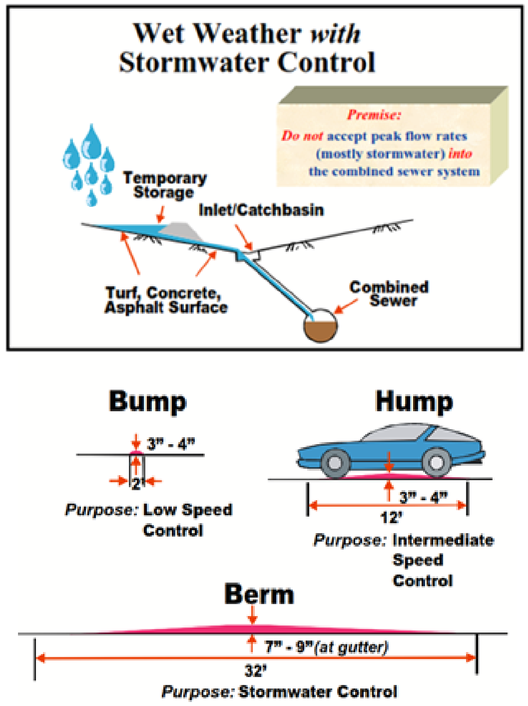

Fig. 5. Control of peak rates of stormwater runoff can, in concept, mitigate surcharging of combined sewer systems. Example of gentler berm as a stormwater control device [17].

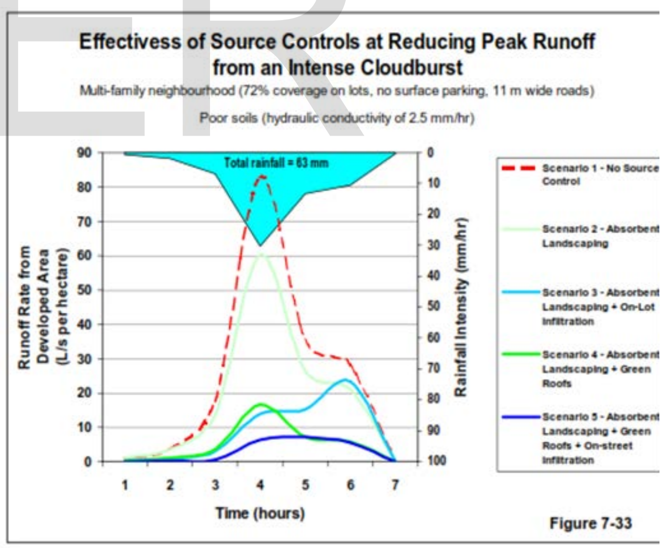

Fig. 6. Effectiveness of source controls at reducing peak runoff from intense cloudburst [15].

duration storm) which could cause significant drainage problems, shown (Figure 6) how the following source control scenarios would be at reducing the runoff from the event occurred in White Rock City (British Columbia, Canada) on June 8th, 1999 [15]:

- *__Scenario 1__*- No Source Control.
- *__Scenario 2__*- With 300 mm of absorbent soil;
- *__Scenario 3__* - With an absorbent soil (300 mm of soil depth) and infiltration on lot covering 10% of the lot area.
- *__Scenario 4__* - Same as Scenario 2 with green roofs (300 mm

of soil depth);

- ***Scenario 5***- Same scenario 4 but with infiltration for flows generated by roads on the street;

The examination the different hydrographs shown that it would indeed be reduced sufficiently flows and runoff volumes to offset anticipated increases due to CC since the reduction percentages vary from 27% for Scenario 2 to 92% for scenario 5. This case study shows that source controls can be very effective at reducing runoff rate from cloudbursts, and thus partially mitigating some of the anticipated effects of CC.

5 Conclusion

Essentially, there are two scenarios for the application of different techniques to compensate for the effects related to climate change: the case of projected networks and the case of existing networks as desired rehabilitated [4][5][20][21]. As previously noted, the planning and design of projected networks offer more flexibility because several different measures that are available will often apply [5][9][15][22]. It is therefore in this case to consider when designing the increases that are planned and forecast infrastructure accordingly. Emphasize again that we should give special attention to the BMPs specially the source controls, which are little used in the current practice of extended way but offer several advantages [21][22]. By simply changing the types of planned urban development to encourage local BMPs (infiltration, green roofs,.etc), we will come to compensate hydrological impacts of climate change without having to increase the dimensions of the proposed networks [5] [14][15][18].

It should be noted that recourse to a replacement of existing pipelines in urban drainage system should obviously not be regarded as the only solution, since this measure is costly and can, in some cases, shift the problem to the downstream [14]. Moreover, this overall approach goes against the new trends that favor more rapid and efficient drainage which is often the cause of problems observed in receiving environments [5] [9]. in this sense the control at source appears as a measurement with very good cost / benefit ratio and should therefore be given priority with a perspective on the combination of several measures for good integration in urban drainage system [5][21].

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