IMPACT OF FUTURE SCENARIOS ON THE URBAN RUNOFF PRODUCTION

IMPATTI DI SCENARI FUTURI SULLA PRODUZIONE DEI DEFLUSSI URBANI

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ABSTRACT ESTESO

L'aumento di intensità e variabilità dei processi idrologici previsto a livello globale anche dalla recentissima pubblicazione dell'IPCC (IPCC, 2021) rappresenta per i centri urbani un potenziale incremento di vulnerabilità rispetto al rischio di piene urbane. A livello europeo, la dispersione urbana e il conseguente consumo di suolo aumentano ulteriormente la pressione sui sistemi di drenaggio urbano, spesso inadeguati sia alle sollecitazioni meteoriche più intense che alla maggiore impermeabilizzazione dei bacini drenati.

Per quanto riguarda la situazione italiana, negli ultimi anni diverse sono le città italiane che stanno vivendo un aumento di frequenza di eventi idrometeorologici particolarmente intensi e dannosi, con notevole disagio per la popolazione. Le proiezioni climatiche unite alla previsione di un aumento della popolazione residente nei centri urbani già consolidati rendono gli stessi centri maggiormente vulnerabili nel futuro. In linea con l'obiettivo di ridurre al massimo la dispersione delle aree urbane e il consumo di suolo, alcune regioni italiane hanno introdotto regolamenti che applicano il principio di invarianza idraulica e idrologica per limitare l'ingresso nella rete drenante dei deflussi urbani, sia in termini di volumi che di portate di picco. Non vengono invece contemplati gli effetti del cambiamento climatico, che possono ulteriormente aggravare la situazione.

Perché il rispetto del principio di invarianza idraulica e idrologica venga garantito anche a medio e lungo termine è utile considerare il potenziale impatto degli scenari futuri per valutare con sufficiente margine di sicurezza gli interventi utili alla mitigazione del rischio di piena. Tra l'altro, la valutazione integrata può portare a nuove scelte progettuali, più flessibili, con molteplici benefici, come quelli che caratterizzano le nature-based solutions, promosse sia a livello internazionale che nazionale come strumenti di adattamento e mitigazione degli effetti del cambiamento climatico in aree urbane.

Con riferimento alla città di Brescia, viene analizzato un caso di studio ipotetico che porta al dimensionamento di una vasca di laminazione secondo il regolamento regionale lombardo, più cautelativo di altri perché fa riferimento ad una situazione precedente all'urbanizzazione e non a quella precedente il solo intervento in progetto. Viene quindi suggerita una valutazione preliminare dell'impatto del cambiamento climatico sulla base di alcuni risultati di un modello climatico a scala regionale corrispondenti a scenari futuri precedentemente individuati. Pur nell'incertezza delle proiezioni climatiche, in particolar modo di quelle relative alla precipitazione, la valutazione preliminare evidenzia l'opportunità di tener presente gli scenari climatici futuri in fase di dimensionamento delle opere, per assicurare una maggiore resilienza dei sistemi di drenaggio urbano.

ABSTRACT

In the last years several Italian cities are experiencing an increased frequency of occurrence of intense and damaging hydrometeorological events, leading to quite uncomfortable situations for the citizens. Climate projections, together with the expected increase of the population living in cities, make them even more vulnerable in the future. To preserve the hydraulic and hydrologic invariance principle in the middle and long term, the potential impact of future scenarios should be taken into account, in order to safely design interventions aiming at mitigating the risk. The integrated evaluation can also lead to new design solutions, more flexible, providing multiple benefits, such as nature-based solutions.

With reference to Brescia, a hypothetic case study is analysed, including the sizing of a routing tank required by the local regional regulation. Then a preliminary evaluation of the climate change impact is attempted.

1. Introduction

Headline statements of the last assessment report published by Intergovernmental Panel on Climate Change (IPCC, 2021) include a reference to the global water cycle in the possible future climate, namely "Continued global warming is projected to further intensify the global water cycle, including its variability, global monsoon precipitation and the severity of wet and dry events". Again, concerning climate information for risk assessment and regional adaptation, IPCC headline statements report that "Natural drivers and internal variability will modulate human-caused changes, especially at regional scales and in the near term, with little effect on centennial global warming. These modulations are important to consider in planning for the full range of possible changes."

On the other hand, in the last decades urban sprawl has strongly affected Europe, where the residential density of several cities has strongly decreased from the mid-1950s to the late 1990s. This occurred also in Italy and besides in Palermo where the residential density has more than halved (EEA, 2006). The land use change consequent to the urban development (see also Melchiorri et al., 2018) are making European cities more and more vulnerable to intense meteorological events, mainly because of the decrease in available retention areas (EEA, 2012).

These are the main challenges in stormwater management that also Italian cities are facing. Reasons for failing the management of high stormwater flows lie in the insufficient sizing of sewer pipes, as well as in the inadequacy of the cross-sections of some of the main collectors and the scarce maintenance of the whole system. In fact, in old urban areas the combined sewer network mostly consist of historical collectors, dating back to the early years of the last century. Moreover, information on the sewer network and its monitoring system is often lacking. On the other hand, soil sealing resulting from the intense urban development over the last 20 years was not combined with a proper adaptation of the drainage network, consisting in most cases of a man-made pipe network strongly connected with a natural drainage one. As a consequence, urban areas are affected by widespread flooding, with increasing frequency of occurrence in future scenarios (Dada et al., 2021). This requires the adoption of adaptation and mitigation solutions to be included in updated urban planning tools within integrated frameworks, such as the one based on the idea of Water Sensitive Cities (WSC), integrating urban planning with environmental engineering, social science, and community engagement and developing new technologies, strategies, policies, and tools that aim to improve the livability, sustainability, and resilience of cities (Wong and Brown, 2009; Hattum et al., 2016). In line with these integrated frameworks, nature-based solutions (NBS), rather than more conventional engineering ones, are being suggested both at the international and national level as climate change adaption and mitigation measures, providing multiple benefits beyond the hydraulic technical solutions (WWAP, 2018; MATTM, 2018; European Commission, 2012; Grossi et al., 2021; Piro et al., 2019). In fact, water sensitive urban design (WSUD) implies a contemporary planning and engineering design approach that integrates urban planning with the management, protection, and conservation of the water cycle and ensures a sensitive urban water management to natural hydrological and ecological processes (Wong, 2015).

In this perspective, compliance with the hydraulic and hydrologic invariance is a fundamental feature of sustainable urban development: both runoff peak flows and volumes need to be limited to their pre-urbanization level (Berteni et al., 2021). Moreover, sustainability including climate resilience requires that also the potential effects of climate change are accounted for.

In this work, the hydraulic and hydrologic invariance concept, as translated into the recent regulation issued by Regione Lombardia (BURL, 2019), is applied to a hypothetic urban development area located in Brescia and the required water storage volume is being evaluated in the current and future climate scenarios.

2. The case study

A hypothetic urban development area, 2000 m^2 wide, is being considered in Brescia (Regione Lombardia), with a new industrial building covering half of the area which is currently not developed. After the intervention, the urban area will consist of 1000 m^2 of pervious area and 1000 m^2 of impervious area. The water table is supposed to be very close to the soil surface (depth < 1m) and the surface layer permeability is assumed to be medium-low (as it were soil consisting of silt).

Therefore, to comply with the hydraulic and hydrologic invariance, the design of a routing reservoir is required, outflowing routed flows in a surface water body, but no infiltration device can be included in the urban development design to decrease the volume of water storage.

Regione Lombardia recently issued a regional regulation named ‘Regolamento Regionale del 23 novembre 2017 n.7’ (updated on 21/12/2019 - BURL, 2019), reporting criteria and methodologies to comply with the hydraulic and hydrologic invariance in accordance with the article 58 bis of the regional law of 11th March 2005 n. 12 (the so called ‘Law for the territorial administration’).

2.1 The regional regulation

The regional regulation mentioned above is quite detailed and it splits the regional territory in a few implementation classes, as summarized in Table 1.

Implementation class (potential sealing)	Intervention area S	φ [-]	Evaluation methodology for A and B settings	Evaluation methodology for C setting
Any	S ≤ 0,03 ha	any	R*	R*
Low	0,03 < S ≤ 0,1 ha	≤ 0,4	R**	R**
Medium	0,03 < S ≤ 0,1 ha	> 0,4	M.P. + R**	M.P. + R**
Medium	0,1 < S ≤ 1 ha	any	M.P. + R**	M.P. + R**
Medium	1 < S ≤ 10 ha	≤ 0,4	M.P. + R**	M.P. + R**
High	1 < S ≤ 10 ha	> 0,4	P.D. + R**	P.D. + R**
High	S > 10 ha	any	P.D. + R**	P.D. + R**

Table 1 - Splitting of the regional territory in implementation classes and territorial settings (“S” is the intervention area, “φ” is the weighed average of the runoff coefficient, “A setting”: areas with highly critical hydraulic issues, “B setting”: areas with medium level of critical hydraulic issues, “C setting”: areas with low level of critical hydraulic issues). M.P.: simplified procedure based only on rainfall amount (leaving appart the effect of any rainfall-runoff transformation) . P.D.: detailed procedure. R*: minimum value art. 12, comma 1. R**: minimum value art. 12 comma 2

Tab. 1 - *Suddivisione del territorio regionale in classi di intervento e ambiti territoriali (“S” è la superficie interessata dall’intervento, “φ” è il coefficiente di deflusso medio ponderale, “ambito territoriale A”: aree ad alta criticità idraulica, “ambito territoriale B”: aree a media criticità idraulica, “ambito territoriale C”: aree a bassa criticità idraulica). M.P.: Metodo delle sole piogge. P.D.: Procedura dettagliata. R*: requisito minimo art. 12, comma 1. R**: requisiti minimi art. 12 comma 2*

On the basis of the territorial splitting in several implementation settings, the case study area is assigned to the class featuring a medium level of critical issues. Therefore, a minimum routing volume of 500 m^3/ha is required, together with a maximum stormwater outflow of 20 l/s/ha (for each impervious drained hectare of the urban area). The impervious area is the result of the product between the total drained area and the weighted average of its runoff coefficient. According to the regional rules, runoff coefficient values of 1 and 0.3 were respectively assumed for impervious areas (e.g. roofs, road pavement, parking lots) and pervious areas (e.g. green areas with storage elements and pipes). When the intervention area, the average runoff coefficient and the territorial settings are known, the application of the regulation leads to the selection of the intervention class (for the case study the class is “medium potential soil sealing”) and of the methodology to compute the routing storage volume (for the case study it is the simplified method based only on rainfall amount and described in detail in the text of the regulation), that in any case has to be higher than the minimum value mentioned above. Figure 1 graphically shows how the simplified methodology based only on the rainfall amount works.

According to the rules, the sizing of the routing devices and its validation need to refer to return periods of 50 and 100 years respectively. Parameters of rainfall depth-duration-frequency curves used to build design storms are set on the basis of the data provided by the regional environment protection agency. Emptying of the routing tank has to take not more than 48 hours, so that the routing volume is soon available again. It is also worth to notice that, according to the severity of their

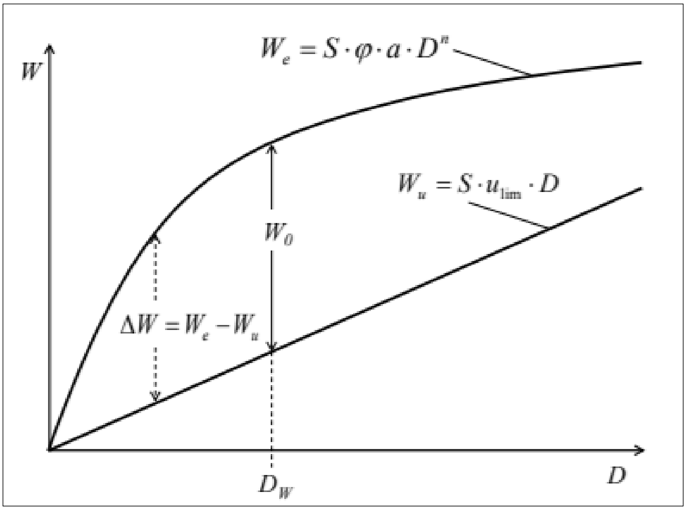

Figure 1 - Graphical explanation of the simplified methodology based only on rainfall amount to identify the duration of the critical rainfall event D_w and the corresponding maximum routing storage volume W_0 ("W" is the storage volume, "W_e" is the volume of stormwater entering the system as a function of rainfall event duration, "W_u" is the volume released from the system during the rainfall event, "ΔW" is the difference between W_e and W_u, "S" is the basin drainage surface, "φ" is the runoff coefficient, "D" is the rainfall duration, "a" and "n" are the parameters of the rainfall depth-duration-frequency curve and "u_{lim}" is the admissible outflow. (BURL, 2019)

Fig. 1 - *Spiegazione grafica del metodo delle sole piogge, basata solo sul valore di precipitazioone totale, per determinare la durata dell'evento di precipitazione critico per l'invaso,* D_w*, e il corrispondente volume massimo necessario per la laminazione* W_0 *("W" è il volume di laminazione, "*W_e*" è il volume di pioggia complessivamente entrante nell'invaso di laminazione, espresso in funzione della durata di pioggia, "*W_u*" è il volume di pioggia complessivamente uscito dall'invaso di laminazione nel corso dell'evento meteorico, "*ΔW*" è la differenza tra* W_e *e* W_u*, "S" è la superficie scolante del bacino, "*φ*" è il coefficiente di deflusso, "D" è la durata dell'evento di precipitazione, "a" e "n" sono i parametri della curva di possibilità pluviometrica e "*u_{lim}*" è la portata specifica limite ammissibile allo scarico. (BURL, 2019)*

hydraulically critical issues, municipalities located in Regione Lombardia are required to develop either a Hydraulic Risk Management Plan or a Simplified Document, that may include further requirements for the application of the hydraulic and hydrological invariance principle. This is though assumed to be not occurring for the case study.

3. The future scenarios

Future scenarios can account for both new urban development areas and climate projections (or climate change scenarios). Integrated approaches such as Water Sensitive Cities may be used to plan a more resilient and sustainable development (Dada et al., 2021). On the other hand, Italian regional rules aiming at mitigating the hydraulic risk in urban areas are not accounting for climate projections, that may lead to different sizing of the technical solutions, either conventional or nature-based.

For a preliminary evaluation of what could be the effect of climate change on the required water storage volumes, CORDEX (www.cordex.org) climate projections in Brescia and its surroundings for three different Representative Concentration Pathways (RCP2.6, RCP4.5 and RCP8.5 from 2041 to 2060) set by IPCC are analysed. RCPs describe the pathways of the additional radiative forcing caused by anthropogenic activity till the end of the 21st century. In this study, climate projections were selected that resulted from the following modelling options:

- Global Climate Model (GCM): ICHEC-EC-EARTH (www.ec-earth.org);
- Regional Climate Model (RCM): RCA4 (Samuelsson et al., 2015);
- Spatial Domain: EUR-11i (https://portal.enes.org/).

Average precipitation correction factors are derived for the four RCM grid points closer to the hypothetic urban development area (see Figure 2) and they are used to adjust rainfall depth-duration- frequency curves provided by the regional environment protection agency. Correction factors express precipitation change between the current and the future climate for each month; therefore, they are calculated by comparing future simulations (from 2041 to 2060) and historical scenario (from 1981 to 2005) in the CORDEX dataset. Maximum precipitation correction factors of 1.18, 0.99 and 1.16 were derived for RCP2.6, RCP4.5 and RCP8.5 respectively.

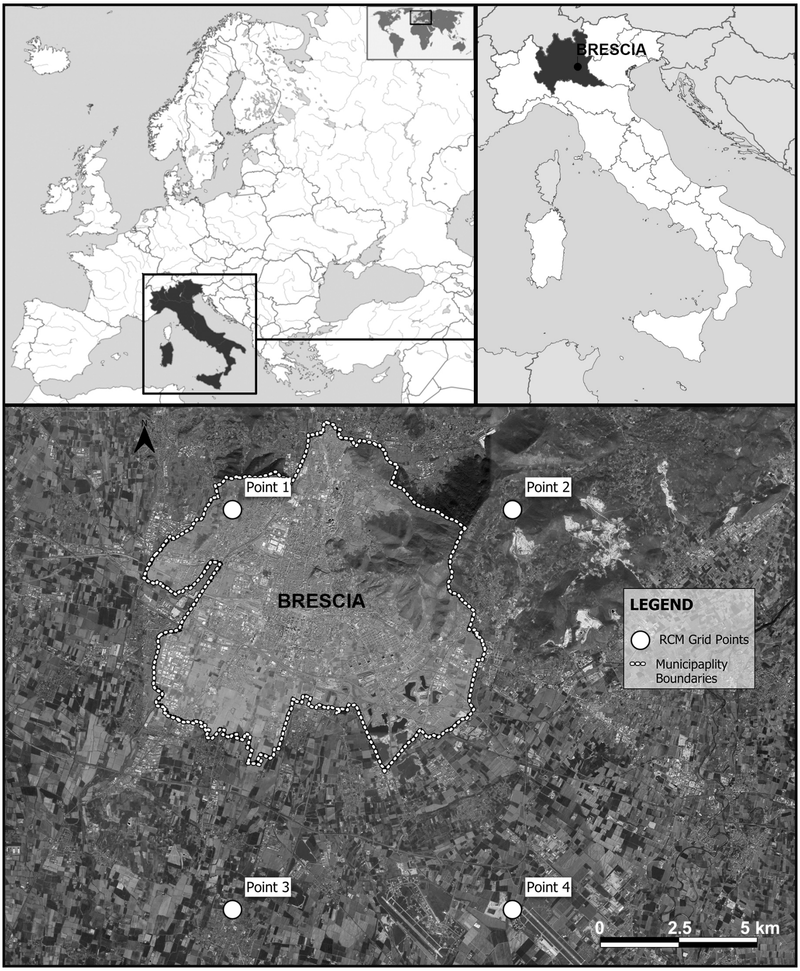

Figure 2 - Position of RCM (Regional Climate Model) grid points in Brescia and its surroundings, closer to the study area (base map from Google Maps, accessed on 2 November 2021)

Fig. 2 - *Posizionamento dei punti della griglia RCM (Modello Climatico Regionale) che si trovano più prossimi all'area di studio, a Brescia e nei suoi dintorni (base cartografica da Google Maps, accesso il 2 Novembre 2021)*

4. Results and discussion

Table 2 shows the results of the rule implementation to the case study: the diameter of the outflow pipe section of the tank was computed on the basis of the outflow law for a circular orifice, setting the coefficient value and the orifice depth to 0.6 m and 1 m respectively and referring to a return period of 100 years. The applied regional rule is quite precautionary in that it refers to the pre-development conditions and not to the conditions before the last planned intervention, as other Italian regions do. This would lead to quite different results if the new development was planned in a developed area, instead of a green area as in the case study (Berteni et al., 2021).

Q_{max} [l/s]	V_{min} [m³]	t [h]	D_i [mm]	φ [-]
2,6	76,3	8,2	35	0,65

Table 2 - Results of the regional rule application to the case study in the actual climate ("Q_{max}" is the maximum admitted outflow, "V_{min}" is the minimum value of the required storage volume, "t" is the tank emptying time when the stored volume is V_{min}, "D_i" is the theoretical diameter of the outflow pipe, "φ" is the runoff coefficient after the intervention)

Tab. 2 - *Risultati ottenuti dall'applicazione del regolamento regionale al caso di studio, considerando le attuali condizioni climatiche ("Q_{max}" è la portata limite ammissibile allo scarico, "V_{min}" è il volume minimo dell'invaso di laminazione, "t" è il tempo di svuotamento dell'invaso avente volume pari a V_{min}, "D_i" è il diametro teorico della tubazione in uscita dall'invaso, "φ" è il coefficiente di deflusso medio ponderale del bacino afferente all'invaso dopo l'intervento di trasformazione)*

The minimum value of the storage volume would though increase in future climate scenarios. In fact, if the precipitation was corrected according to CORDEX data for Brescia, in the most precautionary case of RCP2.6 the needed storage volume would have to be increased up to 95.4 m³, that is by 25%.

Namely precipitation correction factors for RCP2.6 turn out to be the highest for all the four considered grid points.

5. Conclusions

A hypothetic case study was set for the implementation of regional rules ensuring the compliance with the hydraulic and hydrologic invariance principle with the aim of mitigating the hydraulic risk in urban areas. Required storage volumes were also computed for the future climate, on the basis of CORDEX data, providing regional climate projections for RCP2.6, RCP4.5 and RCP8.5.

For an urban development area of 2000 m² located in Brescia, regional rules require a storage volume of 76.3 m³ in the actual climate, to be increased by 25% in RCP 2.6. Future climate scenarios should then be taken into account together with the planned development areas to ensure climate resilience of the drainage system.

Future development of this study might include the application of the detailed procedure, which is described in the regional regulation, to a hypothetic urban development area falling in the "high potential soil sealing" class (see Table 1). This intervention class may require higher storage volume and diameter of the outflow pipe, both in the current and in the future climate scenarios.

Nevertheless, different methodologies as those suggested by different regional rules, even if still based on the same concept of 'no more urban development', may lead to substantially different results.

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