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Implementing green infrastructure for stormwater management and combined sewer overflow control

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Abstract: Green infrastructure has been used in many countries as a source control measure of stormwater runoff. Chicago is one of the many cities that have a combined sewer system and frequently faces overflows. This study proposes a stormwater management system along Chicago's riverfront. The area of green infrastructure to be studied (77,300 m^2) is composed of wetland, pond and permeable pavement and was designed to collect, store, treat and discharge or reuse 23,620,000 litres of water. A 49.1% reduction in runoff has been determined for the wetland/pond system compared to the current scenario. The permeable pavement, in turn, infiltrated and stored on average, 325,000 litres of stormwater daily. The stormwater collected from the pavement would be used for non-potable purposes, providing potable water savings up to 6.5%, and serving more than 13,000 people of the neighbourhood. The findings highlight the great potential of green infrastructure to improve stormwater management.

Keywords: green infrastructure; wetland; pond; permeable pavement; stormwater management; combined sewer overflow; CSO.

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1 Introduction

The rapid growth of urban areas has brought severe problems related to the decrease in the quality of water resources and an increase in the number of localised floods. The unrestrained rise in impermeable areas such as roads, roofs and other impermeable surfaces has been causing a reduction in the infiltration capacity and an increase of stormwater runoff in urban centres (William et al., 2017; O'Donnell et al., 2017; Hoang and Fenner, 2016). Such runoff often carries large amounts of contaminants and pollutants, including suspended solids, hydrocarbons, heavy metals (i.e., lead, zinc, chromium, cadmium and copper), and oils and greases (Antunes et al., 2016). Besides, in cities with combined sewer systems, stormwater runoff is combined with black water and grey water and sent to the wastewater treatment plant. In consequence, during peak flow, the combined sewer network has the potential to be overwhelmed and flood, releasing harmful pollutants into the environment.

Also, global warming may lead to an increase in short-term floods. Several studies point out that there is a strong correlation between peak rainfall intensity and high temperatures (Wasko and Sharma, 2015; Akasofu, 2013). With the rise in the number of floods, it is necessary to implement new urban drainage systems, capable of restoring the natural hydrological cycle in urban centres. Green infrastructure facilities are examples of systems that fulfil this function, reducing the possibility of overloading combined sewer systems by treating water locally (Stovin and Ashley, 2019; Dolowitz et al., 2018).

Green infrastructure is the designation applied to a series of source control measures that employ natural processes to reduce stormwater runoff, developing infiltration, evapotranspiration and the harvest and use of stormwater in a decentralised way, by individual lots distributed throughout the urban watershed (De Sousa et al., 2012). Examples of green infrastructure for stormwater management include green roofs (roofs covered by vegetation, which infiltrate and evapotranspire the rainwater stored), bioretention basins (vegetated basins that collect and treat runoff by sedimentation, infiltration and evapotranspiration), and permeable pavement (pavement with porosity and permeability high enough to percolate and temporarily accumulate stormwater). Some studies in the literature show the benefits of the implementation of green infrastructure, including improved community aesthetics (Lovell and Taylor, 2013), livability (Ward et al., 2019), real estate value (Netusil et al., 2014), and quality of life and ecosystems (Coutts and Hahn, 2015).

Lewellyn et al. (2016) implemented an infiltration trench in southeastern Pennsylvania and concluded that the system consistently met the volume reduction design goals, mitigating storm runoff during large extreme events. The system captured and removed at least 59% of the volume of every storm event analysed, with an average of 93% capture for events greater than the design volume of 2.5 cm. Emerson and Traver (2008) proposed changes in the existing conventional asphalt paved area and a curbed turf area in the campus of a university. They implemented two green infrastructure facilities: a pervious concrete infiltration basin and a bioinfiltration traffic island. The hydraulic conductivity was 7.2 and 13 cm/day, respectively, during the 4-year monitoring time. The results show no discernible systematic decrease in performance over the monitoring period, even without any maintenance to the infiltration surfaces performed for either green infrastructure. Other studies also found suitable results for green infrastructure in reducing stormwater runoff (Jia et al., 2016; Pappalardo et al., 2017) and improvement in stormwater quality (Davis et al., 2010; Martínez et al., 2018). De Sousa et al. (2012) concluded that watershed managers who aim to reduce CSOs and reduce carbon footprints should opt for green facilities over grey ones. Also, under certain conditions, the implementation of green infrastructure could be more cost-effective at reducing combined sewer overflows (CSOs) compared to the conventional infrastructure (Montalto et al., 2007). These results demonstrate that green infrastructure can reduce significant runoff volumes during larger events and that new design strategies are needed to better understand its performance.

Several studies demonstrate that the use of stormwater collected from roofs for non-potable purposes brings suitable results concerning the potential for potable water savings in buildings. Such potential helps to decrease runoff and, consequently, assists in controlling CSOs (Hammes et al., 2020; Antunes and Ghisi, 2020). However, few studies have evaluated the use of stormwater collected from permeable pavements in non-potable water uses in buildings (i.e., toilet flushing, garden watering, cleaning outdoor areas, among others). Vaz et al. (2020) concluded that the use of stormwater collected from a permeable pavement in a parking lot of a public university could provide up to 42% potable water savings. In comparison, Hammes et al. (2018) found values of up to 54%. Although little explored, the studies cited show high potential for potable water savings, which could be joined to the concept of CSO control.

The reliability of the control of CSOs obtained with green infrastructure will only be known with certainty after the implementation of a sufficient density of green infrastructure facilities and a real watershed response (De Sousa et al., 2012). Thus, this study proposes the development of a stormwater management system composed of green infrastructure facilities (wetland, pond and permeable pavement) to determine the capacity to collect and treat water and the reduction in the amount of stormwater runoff achieved by the facilities. Also, the system considers the use of stormwater harvested from the permeable pavement in non-potable water uses in residential buildings, a question that was insufficiently explored by the literature. The study was carried out in the city of Chicago, which faces problems with CSOs (Zhu et al., 2017) and climate change (Platt, 2018). The research aims to contribute to the scientific advancement of state of the art, bringing current data and providing instructions for choosing more sustainable drainage systems, which improves stormwater management in urban centres.

2 Method

The study considers the implementation of a stormwater management system containing green infrastructure (wetland, pond and permeable pavement) that collect, store, treat and discharge or reuse stormwater. The system is placed in an existing vacant industrial area, the Bubbly Creek area, Chicago.

2.1 Case study: bubbly creek area, Chicago

Bubbly Creek is a branch of the South Fork of the Chicago River. The name derives from the gases bubbling in the river, which result from years of dumping the waste (blood, entrails, and various chemical wastes) of the local meatpacking businesses since the early 20th century (Sinclair, 1971).

The impact of Bubbly Creek's contamination is present to this day. It is still possible to see the bubbles in the river as a result of a large amount of methane and hydrogen sulphide gas dumped before. The South Fork area can be considered the most polluted region of the Chicago River once it contained the highest level of faecal coliform bacteria and also the lowest dissolved oxygen level (CSU, 2004).

The area is primarily surrounded by residential, industrial and commercial areas. Bubbly Creek has currently eight CSO outfalls. The stormwater management system proposed combines green infrastructure to manage stormwater and urban runoff. The city currently addresses stormwater management mostly through grey strategies. The proposed stormwater management system includes wetland and pond as natural detention and treatment systems, and the implementation of permeable pavement in roads and paving to filtrate, store and use stormwater in activities that do not require potable water in buildings.

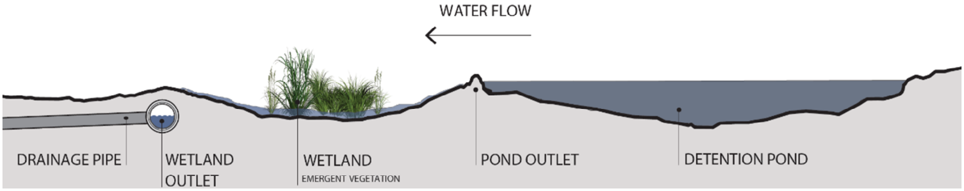
2.2 Stormwater management: wetland/pond system

The system proposes to separate stormwater from the existing sewer system and collect it inside a park, which would be part of a bigger system extending along the Chicago River. The stored water is treated in a wetland/pond system, where the pollutants and sediments are removed. After that, the water is slowed discharged into Bubbly Creek, cleaner and more oxygenated. Figure 1 illustrates the stormwater management system proposed and Figure 2 represents a scheme of the system.

Figure 1 Stormwater management, (a) top view and (b) section

(a) (b)

Figure 2 Scheme of the wetland/pond system inside the park (see online version for colours)



The designed system can be divided into four steps:

1. Collecting: stormwater is collected using the site inclination of the park vegetated area and directed to the detention pond.
2. Storing: the pond stores temporarily and partially treats the collected water through sedimentation.
3. Treating: the water flows through a wetland. Stormwater wetlands are flood areas with flowing water that contain specific plants adapted to saturated soil conditions and capable of removing pollutants such as total suspended solids, heavy metals, phosphorus, nitrogen, oils and faecal coliforms. These plants also oxygenate the water (Cohen and Brown, 2007).
4. Discharging: finally, the water is released into Bubbly Creek through drainage pipes located at the border of the wetland.

2.2.1 Water treatment capacity of the wetland/pond system

The minimum water treatment capacity of the designed wetland/pond system was calculated based on the US Environmental Protection Agency (EPA) parameters (Clar et al., 2004) and the New York State Stormwater Management Design Manual (Department of Environmental Conservation, 2015), according to equations (1) and (2). Note that equation (2) is modified in this study to be presented in SI units.

$$R_v = 0.05 + 0.009 * I \tag{1}$$

where R_v is the storm runoff coefficient (dimensionless); I is the site imperviousness (%).

$$V_t = \left[(S_t * R_v * A) / 12 \right] * (7{,}784) \tag{2}$$

where V_t is the treatment volume (m^3); S_t is the storm used as the sizing criterion, 2-year, 24-hours rain event (mm); A is the contributing area (m^2).

The treatment volume calculated through equation (2) considered the minimal parameters (2-year, 24-hours rain event). We also calculated the real volume that the proposed system can treat. It was defined that the pond stores 70% of the water volume and the wetland 30%, following the Metropolitan Council (2020) recommendations. The pond was designed with a 1.5 m depth and the wetland with 0.5 m. The superficial area and the maximum treatment volume were defined according to Equations (3) to (8).

$$A = PA + WA \tag{3}$$

$$PV = 0.7 * V \tag{4}$$

$$PV = PA * Pd \tag{5}$$

$$WV = 0.3 * V \tag{6}$$

$$WV = WA * Wd \tag{7}$$

$$V = PV + WV \tag{8}$$

where A is the wetland/pond system area (m^2); PA is the pond area (m^2); WA is the wetland area (m^2); PV is the pond volume (m^3); V is the wetland/pond system volume (m^3); Pd is the pond depth (m); WV is the wetland volume (m^3); Wd is the wetland depth (m).

2.2.2 National stormwater calculator

To check the efficiency of the proposed wetland/pond system in runoff reduction during heavy storms, the National Stormwater Calculator – a software from the Environmental Protection Agency, version 2.0.0.1 – was used (US EPA, 2020). This software estimates the amount of runoff produced in a site and how the rainfall is distributed, showing quantitative results (in volume of water) for infiltration, detention, evaporation, and runoff. The following parameters were obtained and used to feed the software data: location, soil type and drainage, topography, precipitation, evaporation, land cover, and use of green infrastructure. The Sections 2.2.2.1 to 2.2.2.7 explain how these parameters were obtained and how they were inserted into the software. Two scenarios were simulated, i.e., the current scenario and the proposed one.

2.2.2.1 Summary of site description

Table 1 shows the input values used to run the software for the proposed scenario and the current one. This table summarises the site description in both scenarios.

Table 1 Site description

Parameters	*Proposed scenario*	*Current scenario*
Site area (m^2)	77,300	77,300
Hydrologic soil group	C	C
Hydraulic conductivity (mm/h)	10.2	5.1
Surface slope (%)	2	2
Precipitation data source	Chicago Midway AP	Chicago Midway AP
Evaporation data source	Chicago Midway AP	Chicago Midway AP
% Forest	15	5
% Meadow	0	45
% Lawn	65	0
% Desert	0	0
% Impervious	20	50
Green infrastructure	Proposed scenario	Current scenario
Disconnection	20%	0
Wetlands/ponds	65%	0

2.2.2.2 Location

The first step is to input the location and the area of the site analysed. The site area is 77,300 m^2.

2.2.2.3 Soil type

Two data about soil are required: soil type and hydraulic conductivity. We used the software Web Soil Survey (NRCS, 2020) to get information about soil type and drainage. This software gives information about the hydrologic soil group and drainage coefficient. The hydrologic soil group is C, and the hydraulic conductivity varies from 5.1 to 15.3 mm/h. Group C corresponds to soils with moderately high runoff potential. The group has below-average infiltration after pre-saturation. It comprises shallow soils containing considerable clay and colloids. So, we considered hydrologic soil group C for both scenarios. In the current scenario, 5.1 mm/h was used according to the high runoff potential of the soil. To the proposed scenario, the hydraulic conductivity considered for the soil was 10.2 mm/h (on average), which can be reached with the proposed changes, since the hydraulic conductivity increases with the presence of green infrastructures (Noguchi et al., 1997; Newman et al., 2004; Gadi et al., 2017).

2.2.2.4 Topography

To find information about the topography, the Free Map Tools (2020) database was used. This database provides spot elevations. Multiple spot elevations on the site were checked, and since the slope is less than 2%, the site is classified as flat.

2.2.2.5 Precipitation and evaporation

The software has precipitation and evaporation data measured in many stations. The data used in both scenarios was the one measured in Midway Station, Chicago, because this station is the closest to the site. The data provided by the software was collected from 1994 to 2006.

2.2.2.6 Land cover

In this part, more precise information about the land cover of the site was needed. There are five types of land cover in the software: forest, meadow, lawn, desert, and impervious. For the current scenario, the land cover measured on-site was: ~5% of forest, ~45% of meadow, and ~50% of impervious surface. In the current situation, about half of the site is covered with concrete. For the new scenario, the following values were proposed: 15% of forest, 65% of lawn, and 20% of impervious surface. These values were measured considering the new project system. In the new stormwater management system, the land cover is changed in the whole site, proposing a scenario covered mostly with permeable areas.

2.2.2.7 Green infrastructure

This is the last information needed to run the National Stormwater Calculator. The green infrastructure has the goal to capture and treat the water in the site. None of these structures exists currently. The proposed system will have 65% of its area transformed into a wetland/pond system. Furthermore, the system will have 20% of disconnection in the site, i.e. runoff redirected from impervious areas to flow to the green infrastructure. Once again, the values were measured considering the new project system. Detailed measures of the wetland/pond system can be seen in Section 4.1.

2.2.3 Implementing permeable pavement in roads and paving

The second part of the proposed stormwater management system is the implementation of permeable pavement in roads and paving of the neighbourhood selected as a case study. It was considered that stormwater infiltrated in the pavement would be used for non-potable purposes in residential buildings, such as flushing toilets, cleaning outdoor areas, and garden watering. The selected area is predominantly residential. It was also considered that the amount of stormwater collected would be stored in one or more water reservoirs. The water reservoirs would have to be constructed in the neighbourhood with the volume capacity calculated in Section 3.2. The Netuno computer program, version 4, was used for the assessment of the volume of stormwater harvested for different reservoir capacities (Ghisi and Cordova, 2014). The program was validated by Rocha (2009).

Input data for the computer simulations are daily rainfall, the surface area of roads and paving, daily average potable water demand, stormwater demand (as a percentage of potable water demand) and infiltration rate of the pavement. Simulations for different reservoir capacities were run. In this study, the maximum reservoir capacity assessed was 5,000 m^3, and the interval between each capacity was 500 m^3 (which means that we simulated reservoir capacities with 500 m^3, 1,000 m^3, 1,500 m^3 until 5,000 m^3).

Data on water consumption and water end-uses in Chicago was obtained from the American Water Works Association (AWWA, 2015). Rainfall data of Chicago were obtained from the National Weather Service (2020). Thus, daily rainfall over a period of five years (1 May 2012 to 28 June 2016) was used in the simulations.

To determine the total surface area located in the selected region, a map containing all the roads and paving of the region was used (Open Street Map, 2020). To determine the population of the selected area, we utilised data from the City-Data (2020) database.

The infiltration rate of the permeable pavement was considered equal to 0.8 (80% of infiltration in the paved area), according to studies found in the literature (Antunes et al., 2016; Hammes et al., 2018).

With all these inputs, it was possible to calculate the volume of stormwater stored and the potential for potable water savings in buildings by using the stormwater collected for non-potable purposes.

3 Results and discussion

3.1 Stormwater management: wetland/pond system

The site imperviousness is 20% in the proposed scenario. So, the storm runoff coefficient (R_v) is equal to 0.23, according to equation (1). The area of the wetland/pond system is equal to 50,200 m^2 (approximately 65% of the total site area). Therefore, according to equations (3) to (8), the area of the pond is 28,200 m^2, and the area of the wetland is equal to 22,000 m^2.

The pond was considered to have triangle section, so the volume was calculated using equation (2), resulting in 21,120,000 litres of water, value approximately 27 times higher than the regular water treatment volume of the site.

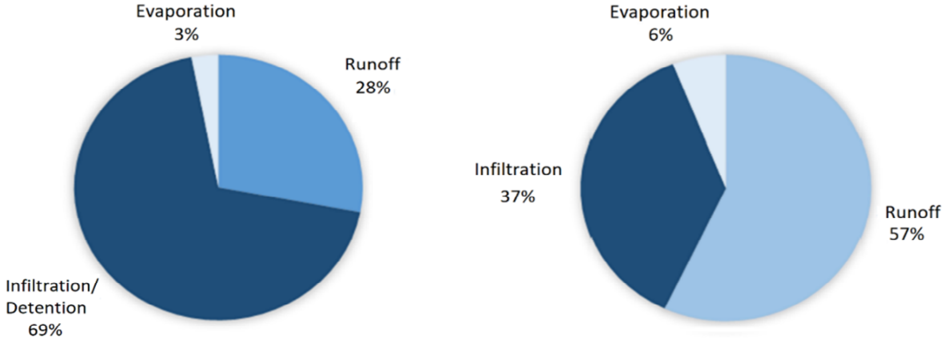
According to Natural Resources Conservation Service (NRCS, 2020), the constructed wetland system must be designed to contain a 2-year 24-hour minimum storm runoff. Also, it is known that precipitation and the treatment capacity varies with the seasons (Emerson and Traver, 2008). Table 2 shows Chicago storm numbers according to the seasons and the respective volume treated by the proposed system using equation (2).

2.5 cm (one inch) of rain over 4,047 m^2 (one acre) generates 102,789 litres of water. The proposed system has an area of 77,300 m^2, so 1,963,269 litres of rain falls on the site with 2.5 cm of rainfall. Figure 3 shows the difference of runoff, detention, infiltration and evaporation for each rain event, comparing the scenarios, calculated by the National Stormwater Calculator.

Table 2 Volume treated by the proposed system

Season	*2-year, 24h storm (mm)*	*Treatment volume (litres)*
Spring	48.8	562,773
Summer	66.3	765,017
Fall	48.8	562,773
Winter	27.7	319,500

Figure 3 Evaporation, detention, infiltration and runoff for each scenario, (a) proposed scenario (b) current scenario (see online version for colours)



(a) (b)

Table 3 Volumes of water generated in 2.5 cm (one inch) of rainfall

Volume (litres)	*Current scenario*	*Proposed scenario*
Generated	1,963,269	1,963,269
Runoff	1,119,066	549,714
Infiltration/detention	726,409	1,354,659
Evaporation	117,798	58,897

With these changes in runoff, detention, infiltration, and evaporation rates, the volumes for each scenario were calculated for rainfall of 2.5 cm in the site (Table 3). So, for this rain event, the proposed scenario would infiltrate or store 628,250 more litres of water in comparison with the current situation. This represents a 49.1% reduction in the runoff volume.

Tilley and Brown (1998) designed constructed wetlands at a neighbourhood scale (< 100 ha) for stormwater treatment and retention of storm runoff for 72 hours at the Biscayne Bay, Florida. Wetland areas were determined as if small wetlands were scattered throughout basins acting as stormwater treatment wetlands for single rainfall events. Pollutant generation was estimated based on the 5-year 24-h design storm. The authors also considered the drainage area, the impervious area as a per cent of drainage area, the total storm rainfall, and the average annual rainfall. They concluded that a total of 65% (11 of 17) of the watersheds needed less than 5% of the basin area as wetland treatment, while only one basin needed more than 10%. Cohen and Brown (2007) assessed a model examining hierarchical wetland networks for watershed stormwater management. The results showed that to prevent overflow during an average rainfall year, a minimum basin coverage of 8.2% was required for the network scenario. For a large rainfall year, in turn, a coverage of 10% resulted in only one overflow event (a 152 mm storm event). For maximum flow events, the network scenario reduced peak flow between 30% and 70% with a mean of 48%. The authors concluded that when small wetlands represent about 60% of the total wetland area, the maximum annual retention is observed.

It is important to highlight that the results reported by Tilley and Brown (1998) and Cohen and Brown (2007) are dependent on location, design storm and local weather. Even though, these results state that the design of the wetland/pond system of the proposed scenario in our case study is in line with other studies found in the literature. Besides, such results demonstrate the effectiveness of wetlands and ponds in storing and attenuating long-period hydrologic flows, which can have a high contribution to CSO control.

3.2 Stormwater harvested from permeable pavements

The amount of water used per resident of Chicago per day, on average, is 465 litres (American Water Works Association of Denver Colorado cited by DePaul Center for Urban Education, 2020). Figure 4 shows the daily rainfall in Chicago during the period of 01 May 2012, to 28 June 2016. The average annual rainfall was equal to 957 mm.

Table 5 Residential end uses of water in the United States

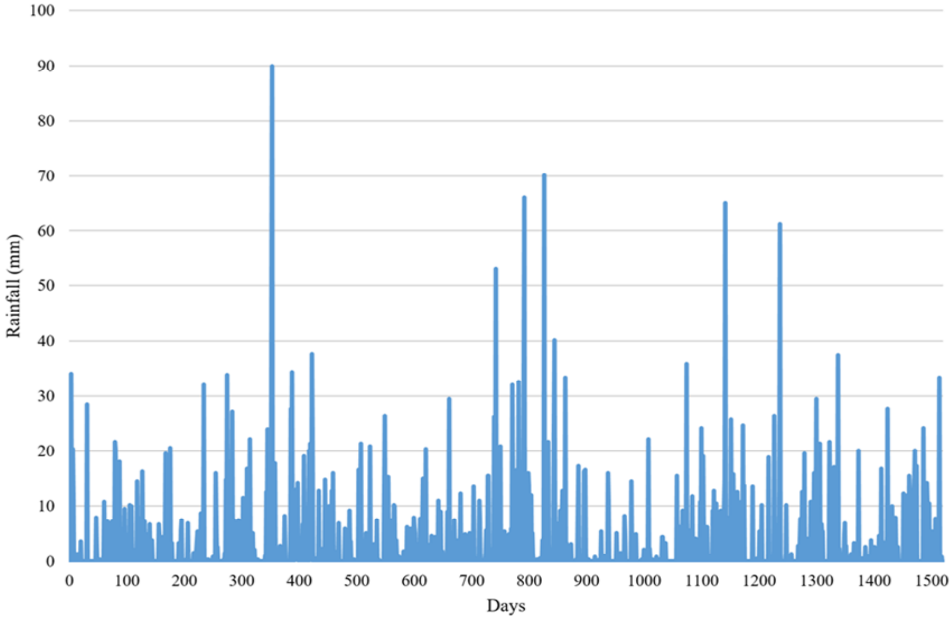
Activity	*Amount of water (litres/habitant/day)*	*Use (%)*
Toilet	111.7	24
Shower	94.9	20
Faucet	88.8	19
Clothes washer	76.7	17
Leak	57.4	12
Other*	17.9	4
Bath	12.2	3
Dishwasher	5.4	1
Total	465.0	100

Note: *The ‘other’ category includes evaporative cooling, humidification, water softening, and other uncategorised indoor uses.

Source: WRF (2020)

The total surface area of roads and paving located in the selected neighbourhood is approximately 266,600 m^2, and the population of the selected area is 13,038 habitants. According to the Water Research Foundation (WRF, 2020), in the USA, 24% of the residential end-uses of water is designated to flushing toilets (Table 5). It means that at least 24% of the potable water uses is designated for non-potable purposes (value that can be even greater if other activities were considered, i.e., lawn watering).

Figure 4 Daily rainfall in Chicago from 1 May 2012 to 28 June 2016 (see online version for colours)



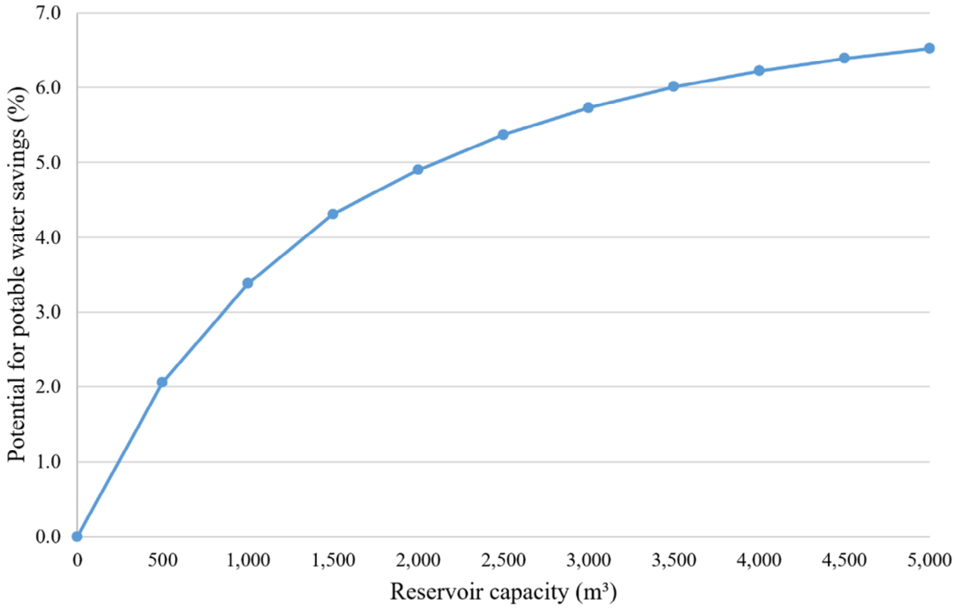
Source: National Weather Service (2020)

Table 6 Potential for potable water savings for different tank capacities and volume of stormwater and potable water consumed

Reservoir capacity (m³)	*Potential for potable water savings (%)*	*Volume of stormwater consumed (litres/day)*
0	0.0	0
500	2.1	124,903
1,000	3.4	205,396
1,500	4.3	261,773
2,000	4.9	297,743
2,500	5.4	325,797
3,000	5.7	347,927
3,500	6.0	364,899
4,000	6.2	377,712
4,500	6.4	387,655
5,000	6.5	395,679

Table 6 shows the relation between the reservoir capacity with the potential for potable water savings and also the volume of stormwater that could be consumed in the neighbourhood buildings. Figure 5 shows how the potential for potable water savings increases with the expansion of the reservoir capacity. If the stormwater stored in the reservoir was used for non-potable purposes (i.e., toilet), the potential for potable water savings would range from 2.1% to 6.5%, depending on the reservoir capacity. For the stormwater management system proposed, we selected a reservoir capacity with the size of an Olympic pool (2,500 m^3). For this capacity, the potable water savings is equal to 5.4%. This capacity could be divided into more than one reservoir and would serve more than 13 thousand inhabitants, saving, on average, more than 325 thousand litres of potable water daily.

Figure 5 Potential for potable water savings for different tank capacities (see online version for colours)



Antunes et al. (2016) assessed the use of stormwater harvested from permeable pavements in buildings in Florianópolis, southern Brazil. They found potential for potable water savings up to 19.4%, 70.0% and 75.7%, in the residential, commercial and public sector, respectively. The community attended by each water storage tank had approximately 500 people, and the daily water consumption per capita was 139 litres/day. The average annual rainfall (2002–2013) was equal to 1,766 mm. A similar study was conducted in Glasgow, Scotland (Antunes et al., 2020). The authors found potential for potable water savings up to 35.3% in residential buildings. The value was obtained for an area representing 0.1% of the total paved area (roads and paving) in Glasgow, with an equivalent neighbourhood population of approximately 600 people, thus representing the optimal cluster size linked to a single water storage tank. The daily water consumption per capita of Glasgow residents is 150 litres/day and the average annual rainfall in the last 15 years was 1,032 mm.

In our case study, the potential for potable water savings in residential buildings by using stormwater harvested from permeable pavements was low (up to 6.5%) compared to the cities of Florianópolis (up to 19.4%) and Glasgow (up to 35.3%). The main reason for this low value is the high daily water consumption of US residents (465 litres/day) in comparison with Florianópolis (139 litres/day) and Glasgow (150 litres/day). Also, the difference in the annual rainfall, in the area of paved roads and water end-uses contributed to the different values found in each study.

Although the US has large water reserves, water scarcity is increasing in the country due to the current high demand for water, which affects its future availability. The southwestern US is already facing this emerging reality. New technologies are necessary to offer alternative water supplies, preventing a crisis from spreading to other regions (McEvoy et al., 2018). Thus, the concept of using stormwater from permeable pavements in buildings joins the water scarcity emerging problem in the US and it is also an important resource to control one of the main causes of CSOs, by infiltrating and storing stormwater in reservoirs.

3.3 Summary of the proposed scenario

Table 7 summarises the area and volume of detention, infiltration and treatment of water for the proposed stormwater management system. In total, 332,200 m^2 were transformed in areas of collecting stormwater (65,600 m^2 in the wetland/pond system and 266,600 m^2 in the permeable pavement system). The systems would be able to store, infiltrate and treat 23,620,000 litres of stormwater. The 2,500,000 litres infiltration capacity provided by the permeable pavement could be even greater. In this calculation, we considered only the capacity of the reservoir, which is used in the stormwater harvest system. Another possibility would be implementing a permeable pavement with partial infiltration into the soil. In this case, the soil type of the subgrade and its permeability should be evaluated.

Table 7 Summary of the area and volume of stormwater treated for the proposed scenario

System 1: Wetland/pond		
Site	*Area (m^2)*	*Detention and treatment of stormwater (litres)*
Park site	77,300	21,120,000
Collecting stormwater area	65,600	
Disconnection	15,400	
Total wetland/pond system	50,200	
Pond	28,200	
Wetland	22,000	
System 2: Permeable pavement		
Site	*Area (m^2)*	*Infiltration and treatment of stormwater (litres)*
Roads and paving in the neighbourhood	266,600	2,500,000 (reservoir capacity; average of 325,000 litres/day)
Total	332,200	23,620,000

3.4 Discussion and conclusions

From January 1st 2007 to March 1st 2018, untreated sewage was dumped into the Chicago River on 660 days. In the location selected as a case study (Bubbly Creek), CSOs happened on 259 days in the same period (MWRD, 2021). This data has not been updated since March 2018 and does not reflect the most recent CSOs.

Comparing the CSO events data obtained from the Metropolitan Water Reclamation District of Greater Chicago (MWRD, 2021) with the precipitation records gathered from the National Weather Service (2020), it can be stated that rain events of as little as 18 mm (0.70 inches) in a 24-hours period can trigger a CSO in the Bubbly Creek. It means that, without any intervention in the existing area, a volume of water equal to 1,374 m^3 in the area of the case study would be enough to cause a CSO event. Considering a 49.1% reduction in the runoff achieved, the implementation of the proposed system would prevent CSO for rain events up to 26.5 mm. For a rain event of this magnitude (26.5 mm), a volume of water equal to 2,048 m^3 would be generated in the area, but only 573 m^3 would be transformed in surface runoff (1.413 m^3 would infiltrate and 61 m^3 would evaporate, on average).

Considering the period between January 1st, 2007 and March 1st, 2018, the proposed system would have prevented CSO events on 113 days, reducing 43.7% the CSO events.

According to the NRDC (2011), the water-related climate changes and impacts in Chicago throughout the 21st century are increased annual precipitation, more frequent and intense storm events, increased flooding, decreased Lake Michigan levels and water supply challenges due to increased droughts. Therefore, it is essential that public agencies increasingly consider the implementation of green infrastructure to improve water infrastructure management through stormwater harvesting in urban centres, and thus, be a source of CSO control.

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