Матеріали XXIII Міжнародної науково-практичної конференції
«Екологія. Людина. Суспільство» (м. Київ, Україна, 7 грудня2023 р.)

Handbook of the XXIII International Science Conference
«Ecology. Human. Society» (December 7, 2023 Kyiv, Ukraine)

ISSN (Online) 2710-3315
DOI: https://doi.org/10.20535/EHS2710-3315.2023.291564

UDC 628.35

# SUSTAINABLE STORMWATER TREATMENT AND MANAGEMENT – SWEDISH EXAMPLES

**Lena JOHANSSON WESTHOLM**
*Mälardalen University*
p.o. box 883 SE-721 23 Västerås, Sweden
**e-mail**: lena.johansson.westholm@mdu.se

Climate changes such as extended periods with increased temperatures, intense precipitation in some areas and severe drought in others are challenges that we must face from now on [1]. In Sweden, many municipalities have adopted municipal plans for climate change adaptation in which increased precipitation causing flooding, elevated temperatures, and rise of the sea level among other climate challenges are included. The plans for climate change adaption must be throughout the built environment when densifying or developing new housing districts and further in existing buildings and in the dimensioning of preparedness [2].

The amounts of stormwater are expected to increase when precipitation events such as cloudburst are expected to be more intense and frequent. Today, our cities consist of paved surfaces, and excess water that falls as precipitation have nowhere to go since sewer systems are not adapted to these water volumes. In Sweden, torrential rain events have occurred in recent years, the cities Malmö and Gävle were hit by cloudbursts in 2014 and 2021, respectively. In both cases, the consequences were detrimental regarding buildings and the technical infrastructure.

In addition to large stormwater volumes, stormwaters are regarded as polluted. The types of pollutants differ depending on the land-use in the area where the stormwater is generated [3]. Typical pollutants present in urban stormwater are sediments, nutrients, e.g., nitrogen (N) and phosphorus (P), heavy metals and organic compounds. These pollutants are regarded as priority pollutants and are found on the list of selected stormwater priority pollutants (SSPP) (ibid.). These pollutants must be removed at the same time as the large water volumes are managed.

There are different options to manage and treat large volumes of stormwater. According to the Swedish Environmental Protection Agency (SEPA), the urban planning must include methods to relieve the existing sewers, but also to treat and manage stormwater in a sustainable way. Stormwater should be regarded as a resource, that it should be treated and managed locally, that cloudbursts are considered, and that the future management of the stormwater facilities can be maintained in a sustainable way. Examples of sustainable solutions for treatment and management of stormwater that fulfil these criteria are for instance constructed wetlands, biofilters of various kinds, green roofs or facilities based on filter substrates. These methods can be regarded as Low Impact Development (LID) solutions, or green technologies, since they aim to increase the infiltration and at the same time, treat the stormwater commonly polluted with nutrients, heavy metals, and organic substances.

LID solutions have been implemented world around. In China, several newly built cities have been constructed as “sponge cities” with extensive green areas, tree plantations and surface water ponds and similar [4]. Stormwater facilities based on filter substrates have been implemented as well

[5]. Constructed wetlands have been built to treat and manage stormwater. In Sweden, sponge cities have not been constructed, but several other LID-solutions have been implemented. Constructed wetland systems and filter substrate-based methods have been constructed in different cities. The aim with the present paper is to provide a range of recent examples of LID-solutions that have been used to treat and manage large volumes of stormwater in Sweden.

Many Swedish municipalities have adopted municipal plans for climate change adaptation, while other municipalities are in the process of developing these plans. The climate change adaptation plans might include different LID-solution facilities to treat and manage stormwater. These facilities look different depending on local conditions. Below, some examples of LID-solution facilities are described.

*Constructed wetlands*

In the city of Västerås, 90 km west of Stockholm, a constructed wetland was built a few years ago [6]. The aim was to treat and manage the stormwater, and at the same time, create an area that could both serve as recreational area and strengthen the biodiversity.

The constructed wetland, the Johannisberg Wetland Park, is a multifunctional park covering 14.5 ha. The Wetland Park receives stormwater (maximum 700 l/s) from a stream originating from the western parts of Västerås city. The park consists of four open ponds that are connected, see Figure 1. In the first pond, the speed of the incoming stormwater from the stream slows down and pollutants that come with the stormwater settles on the bottom of the pond. The second pond is planted with aquatic species that filter the stormwater, thus pollutants such as nitrogen (N) and phosphorus (P) are assimilated by the plants. The third and fourth ponds are sedimentation ponds in which pollutants settle on the bottom of the ponds. Through the pond system, approximately 40-60% of the incoming heavy metals and the phosphorus have been removed [7] before the water is released into Lake Mälaren from which raw water is extracted and used for production of drinking water in Västerås.

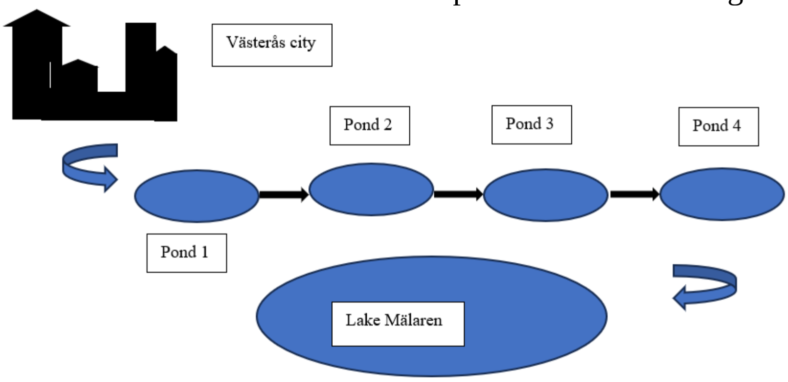


**Figure 1.** Principal design of the Johannisberg Wetland Park in Västerås, Sweden

Except for treating and managing stormwater, the Johannisberg Wetland Park also serves as a recreational area for the citizens in Västerås. There are resting places along the walkways where people can stop for a while, watching the scenery. Further, the wetland park contributes to the biodiversity being the habitat for several bird species [6]. The area is also a habitat for bats.

*Filter-based LID-solutions*

Filter-based solutions have been used world-over to treat and manage stormwater of diverse kinds [5]. The filters have been included in several types of facilities and have for instance been used for treatment of roof runoff or road runoff. Milovanović *et al.* [8] investigated the removal capacity of zeolite regarding copper (Cu) in the first place, but aluminium (Al), sodium (Na) and zinc (Zn) were measured as well. The investigation was carried out as field experiment in Stockholm, it lasted for 16 months, and the authors could report that total-Cu was reduced with 52-82% while the corresponding reduction for dissolved Cu was 48%–85%. Another experiment based on filter materials have been carried out as a pilot-investigation located close to a thoroughfare in Stockholm. In the experiment, stormwater from the thoroughfare was led to a grit-chamber before being fed to sand-filled columns [9]. The aim with the pilot-test was to investigate the removal of copper and zinc from the road runoff. After 7 months, it was reported that the removal was 67% for total-Cu and 93% for total-Zn. The corresponding removal rates were 19% for dissolved Cu and 87% for dissolved Zn, respectively. The sand in the columns still had capacity to remove both Cu and Zn.

*Park areas*

Already existing park areas are in some cases transformed to meet torrential rain events. One such example is the Rålambshov Park located in the central part of Stockholm. The Park has for many years been a popular place to go for recreational purposes, it is located close to Lake Mälaren, thus it is a popular place to go swimming. Other activities and events are frequently arranged in the park [10]. Some of the park areas, e.g., lawns in the middle of the park, have been submerged in water at torrential rain events and at snow-melting periods. In 2017, Stockholm Stad started to adapt the Rålambshov Park to meet these challenges that the climate changes entail regarding large volumes of stormwater. The project to transform the Rålambshov Park consists of three parts: the Cloudburst Pond, the Rain Garden, and the Outlet. The Cloudburst Pond is a low-lying area intended for sports; precipitation that falls can be collected at the bottom of the area that facilitates infiltration to the ground to an underground reservoir filled with crushed stones. The areas adjacent to the sports area have been planted with trees and other vegetation. The Rain Garden receives stormwater from roads next to the park. The stormwater enters the Rain Garden in a large bed of plants, a biofilter, that is composed of walls, gutters, water mirrors and vegetation to make this part of the park nice. The Outlet of the Rålambshov Park is located close to Lake Mälaren. The Outlet in formed in a way that makes it easy for the stormwater to enter the lake. Some pollutants are also treated before the stormwater enters Lake Mälaren. According to [10], the transformation of the Rålambshov Park has been successful since the sewer system has been relieved from parts of the stormwater at the same time as there are green solutions that can both treat and manage large volumes of stormwater in a nice-looking park area.

Climate changes are already here and therefore, it is of uttermost importance to meet the challenges that they entail. Regarding stormwater, there are several natural based methods that could be used for treatment and management of large water volumes caused by torrential rain events. Many of these methods are so called LID-methods indicating they mimic natural processes and in addition, to a low cost.

The type of LID-solutions presented in the paper could be implemented in the already existing built environment provided that given conditions allow for this. Large, constructed wetlands can be built in cities, perhaps not in the centre of the city, but close enough to treat and manage stormwater from the city.

*Constructed wetlands*

Natural wetlands are important in the landscape since they fulfil several functions. Water is treated and can be buffered in the wetlands, and they have high biodiversity. Due to previously extensive drainage and ditching several decades back to obtain more agricultural land, there is a lack of natural wetlands in Sweden. Constructed wetlands can therefore serve as substitutes to regain the lacking functions. The Johannisberg Wetland Park in Västerås city, can thus be regarded as a (constructed) wetland that fulfil the functions that a natural wetland can provide. Regarding treatment of water, a constructed wetland has the advantage that it can be designed to treat specific pollutants. Nutrients and heavy metals as present in the stormwater reaching the wetland, are removed by processes that occur in the ponds. The ponds in the Johannisberg Wetland Park fulfil different purposes, pollutants can settle in some ponds while vegetation assimilate pollutants in another. The removal of pollutants, P, and heavy metals in the Johannisberg Wetland Park, has been reported to be 40-60%. It should be noted that this is a young wetland, when it matures, the removal rates might decrease. A disadvantage with constructed wetlands is that they demand large land areas, and these might not be available within or adjacent to all cities as in Västerås where former agricultural land has been used for the Johannisberg Wetland Park.

*Filter bed solutions*

Filter bed solutions are more convenient to install, they do not need as much surface areas as constructed wetlands. Filter substrates can be incorporated into smaller treatment facilities and examples of these could be green roofs, biofilters or rain gardens. The filter substrates can be chosen depending on the targeted pollutants to be removed [5]. Many of these small treatment facilities remove various pollutants such as nutrients, BOD, COD, heavy metals, and organic compounds, but it is difficult to compare results due do variations in stormwater content, stormwater loading, design of the treatment facility and the filter substrate used. Filter substrates should be based on the capacity of the substrate to remove targeted pollutants, its cost and availability that should be local. Further, it was concluded that the composition of the stormwater, and potential need for pre-treatment must be taken into consideration. The filter bed solutions presented in this paper, e.g., the sand columns [9] and the facility described by [8] are both small-scale pilot studies with advantages and disadvantages. Hallberg et al. [9] could for instance observe that the sand in the filter columns did remove targeted pollutants, but that the sand might be saturated within an abbreviated period when in use. This is normal that the substrate gets saturated, but it is advantageous if the filter substrate could last for longer periods without need for change since the disposal of the saturated substrate might be a disadvantage. However, the use of filter substrates should be further investigated since it has potential as a low-cost solution.

*Park areas*

Park areas already existing are of uttermost importance in cities, they are green oases in the otherwise paved environment. Parks, like natural wetlands, offers several functions, they are advantageous for people’s health, the offer shadow when the sun is shining, they allow precipitation to infiltrate into the ground and the vegetation can assimilate pollutants. Further, parks can reduce noise and they offer a space in the city where people can meet and socialize. In the case of the Rålambshov Park in Stockholm, all of this has been offered for several decades. What is new is that the park, especially some areas, are transformed to treat and manage stormwater in a way that was not needed a few decades ago [10]. Measurements have been taken to prevent flooding of the lawns, otherwise the park is a popular place for the citizens of Stockholm. What could be difficult in an already existing park is the given conditions regarding possibilities to transform parts of the green areas into nice looking parts of the park that fulfils the important task to treat and manage stormwater. Even though it might be difficult to transform an already existing city with paved areas, it is not impossible as shown in Copenhagen where paved areas are being transformed into green areas that can treat and manage torrential rain events when large volumes of stormwater need to be taken care of to prevent destruction of buildings and infrastructure [11]. However, it is costly to transform a paved city into a city with more green areas, in Copenhagen the transformation is expected to go on for roughly a decade to a high cost, but the transformation was regarded as necessary due to the costs that arose during the floodings [11].

As described above, the type of LID-solutions presented in the paper could be implemented in the already existing built environment provided that given conditions allow for this. Large, constructed wetlands can be built in cities, perhaps not in the centre of the city, but close enough to treat and manage stormwater from the city. Filter bed solutions such as biofilters and rain gardens can easily be included in the built environment and transformations of park areas to manage stormwater caused by cloudbursts are also possible to conduct. What type of solutions that should be taken into consideration depends on the composition of the stormwater, the stormwater load, and the given conditions. It is advantageous if the treatment and management of stormwater could be carried out by means of LID-solutions which might be easy to implement in existing parts of the city.

Since we already face the climate conditions, it is necessary that treatment and management of stormwater are taken seriously to avoid flooding in our cities. From the above described, it is obvious that different types of LID-solutions could be used. However, the above presented examples cannot be used to say whether these solutions will work in the long run, there has been no cloudburst in Stockholm for the measurements taken in the Rålambshov Park, the constructed wetland system in Västerås is too young and the research on filter-based substrates for treatment and management of stormwater is rather limited. Further research on these types of solutions is therefore needed.

**References**

1. Doublas-Reyes, F. J., Sörensson, A. A., Almazroui, M., Dosio, A., Gutowski, W. J., Haarsma, R., *et al*. (2021). “Linking global to regional climate change,” in Climate change 2021: The physical science basis. Contribution of working group I to the sixth assessment report of the intergovernmental panel on climate change. Editors P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, et al. (Cambridge University Press).

2. Swedish Civil Contingencies Agency (2015) Intensiv korttidsnederbörd - Riktlinjer för översvämning av urbana områden – förstudie (Intense Short-Term Precipitation - Guidelines for Flooding of Urban Areas – Feasibility Study), Publikationsnummer MSB867 – Maj 2015 ISBN 978-91-7383-580-0 (In Swedish)

3. Eriksson, E., Baun, A., Scholes, L., Ledin, A., Ahlman, S., Revitt, M., Noutsopoulos, C., Mikkelsen, P.S. (2007). Selected stormwater priority pollutants — a European perspective. *Science of the Total Environment* 383:41–51. doi:10.1016/j.scitotenv.2007.05.028

4. Kongjian, Y. (2018). Three comprehensive and innovative strategies to solve the water problems in Xiong’an new district. *Landsc. Archit. Front*., 6(4): 4–13 http://dx.doi.org.ep.bib.mdh.se/10.15302/J-LAF-20180401

5. Johansson Westholm L. (2023), Filter media for storm water treatment in sustainable cities: A review. *Front. Chem. Eng.* 5:1149252. doi: 10.3389/fceng.2023.1149252

6. Andersson, M., Hansen, S., Hedin, Å., Hållmarker, M., and Myhrman, G., (2023) Slutrapport LIFE IP Rich Waters. Anläggande av multifunktionella vattenparker i Uppsala, Västerås och Smedjebacken. Delprojekt C10. (In Swedish, Summary in English)

7. Länsstyrelsen Västmanland, 2021. Invigning av Johannisbergs våtmarkspark (Inauguration of the Johannisberg Wetland Park), Nyheter Invigning av Johannisbergs våtmarkspark - LIFE IP Rich Waters, retrieved November 23, 2023 (In Swedish)

8. Milovanović, I., Hedström, A., Herrmann, I., and Viklander, M. (2022) Performance of a zeolite filter treating copper roof runoff. *Urban Water Journal*, 19(5), 499–508. doi:10.1080/1573062X.2022.2031230

9. Hallberg, M., Renman, G., and Lundbom, T. (2007) Seasonal variations of ten metals in highway runoff and their partition between dissolved and particulate matter. *Water, Air Soil Pollut*. 181, 183–191. doi:10.1007/s11270-006-9289-5

10. Stockholms Stad, 2023. Rålambshovsparken. Rålambshovsparken - Stockholms stad (parker.stockholm), retrieved November 20, 2023 (In Swedish)

11. Københavns Kommunes, S. (2012). Københavns Kommunes Skybrudsplan 2012. (In Danish).