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Sustainable Urban Drainage Infrastructure

Zrównoważona infrastruktura odwadniania miast

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Abstract

Water is one of the most important resources, essential for all life forms. From the perspective of sustainable development there are three important challenges: water availability, water purity, and infrastructure, especially in cities. In this last case the problem is not only with water supply, but also with water runoff. Conventional pipe and curb systems, with their efficient ability to convey runoff rapidly to receiving waters, do not take into consideration these effects and new approaches have been developed in recent years to address these concerns. There is a growing trend towards managing water in a more sustainable way by activating its natural behaviors and process in the urban environment. Control and management near the source is now being promoted intensively and it is viewed in many countries as comprising an appropriate suite of techniques facilitating the similarity of natural processes and minimizing the hydrologic impacts. Such solutions rely on local treatment, retention, re-use, infiltration and conveyance of water runoff in urban areas and thus are in better agreement with sustainable development programme. The paper presents discussion about perspective development of urban drainage systems and a case study of successful implementation of decentralized stormwater system in Augustenborg (Malmö).

Key words: water runoff, stormwater, drainage infrastructure, sustainable development

Streszczenie

Woda stanowi jeden z najważniejszych zasobów, kluczowy dla wszystkich form życia. Z perspektywy rozwoju zrównoważonego występują trzy problemy: dostępność wody, czystość wody i infrastruktura, szczególnie w miastach. W tym ostatnim przypadku wyzwaniem będzie nie tylko pozyskanie wody, ale także jej odpływ. Tradycyjne systemy odwodnienia umożliwiają szybkie odprowadzenie ścieków opadowych do odbiorników rzecznych, nie uwzględniając negatywnego oddziaływania w zakresie jakości wód, co było powodem opracowania nowego podejścia. W ostatnich latach obserwowany jest trend do gospodarowania wodami w bardziej zrównoważony sposób, poprzez odtwarzanie warunków naturalnych w środowisku miejskim. Koncepcja zagospodarowanie wód deszczowych u źródła ich opadu jest obecnie promowana w wielu krajach poprzez stosowanie rozwiązań technicznych, ułatwiających zachowanie naturalnych procesów hydrologicznych i minimalizowanie negatywnych oddziaływań ilościowych i jakościowych. Do tych rozwiązań należy zaliczyć lokalne oczyszczanie ścieków, retencję, gospodarcze wykorzystanie wód, infiltrację oraz transport powierzchniowy wód opadowych. Wdrożenie koncepcji zrównoważonego rozwoju wymaga zaangażowania lokalnej społeczności oraz władz samorządowych. W artykule omówiono przyszłe kierunki rozwoju infrastruktury odwodnienia miast oraz zaprezentowano przykład udanej implementacji koncepcji ich zrównoważonego rozwoju w dzielnicy Augustenborg (Malmö).

Słowa kluczowe: odpływ wody, woda deszczowa, infrastruktura odwadniająca, zrównoważony rozwój

Introduction

No life form can last without water, so this resource plays vital role in our biosphere. From the perspective of sustainable development there are three main challenges connected with water:

The first one is availability. A typical American household is using about 300 liters of water per day. Significant savings are possible, of course, but how do we transfer this to countries, where millions of people have no access to clean water – this makes over a billion people in the world.

The second is water purity. There are many places, where water is available, however is heavily polluted.

The third one is infrastructure connected with water supply and water run-off.

Generally speaking the amount of water available for people is shrinking. The excessive depletion of water is visible in China. In terms of ecology, it should be pointed out that, although the Chinese constitute 20% of the global population, they only have access to 7% of the world's water supply. In the municipalities water management in China is also problematic. For instance, in the very rapidly developing city of Shijiazhuang, characterized by excellent financial results, and inhabited by 2 million people, two-thirds of the groundwater resources have been exhausted. The high quality of the life of the residents of such cities as Shijiazhuang may soon suffer a sudden breakdown. After all, no human settlement can function without a water supply, least of all a two million person agglomeration.

In areas where water availability is higher, there are problems with water pollution, especially in big cities. Low quality of water leaving any town through urban surface water runoff systems means pollution of the environment and have a negative impact on human health, so is affecting basic issues of sustainable development. That's why this paper is concentrated on the problems connected with management of urban runoff water.

The use of combined sewage systems began to die out in the early 20th century, primarily because as cities expanded it became too expensive to construct infrastructure to transport mixed foul and *clean* runoff to wastewater treatment plants on the edge of the city. However, in older urban areas these systems are still used and cause problems with combined sewer overflows discharges. Traditional civil engineering solutions have a number of harmful effects:

- runoff from impervious areas increase the risk of flooding downstream and cause sudden rises in water levels and flow rates in rivers and streams;
- surface water runoff can contain contaminants such as oil, organic matter, pathogens and toxic metals. Although often at low concentrations, cumulatively they can result in poor water quality in rivers and groundwater, affecting biodiversity, amenity value.
- by diverting runoff to piped systems, the amount of water infiltrating the ground is reduced, depleting ground water and reducing flows in watercourses in dry weather.

Although combined sewer systems are replaced by separate systems, the problem of polluted runoff doesn't disappear. Stormwater runoff is the source of contaminants, which can lead to significant pollution of rivers, lakes, estuaries and ground waters (Braune and Wood, 1999). Urban surface water runoff carries not only contaminants such as metals and hydrocarbons but also nutrients and sediments, pathogens and debris (D'Arcy et al., 1998; Miltner et al., 2004). Specially negative is the first flush phenomenon – it means high concentration of pollutants in relatively small volume in the beginning of runoff (Mrowiec, 2010). Steedman (1988) states that the typical result of the effect of urban surface water runoff is that the quality of any given stream is negatively correlated with the degree of urbanisation in its surrounding catchment. Urban expansion in the last decades overload the ageing drainage infrastructure (Jones and Macdonald, 2007). Traditional urban drainage systems are designed to dispose of surface water runoff as quickly as possible from the point at which it has fallen to a discharge point. This concept for runoff water in urban areas results in construction of large diameter sewers, huge storage reservoirs in downstream locations and centralised sewage treatment facilities (Butler and Davies, 2000, Villarreal et al. 2004).

Last decades bring a new approach to design and development of drainage systems aims towards maintaining or restoring a more natural hydrological regime. There has been rapid growth in the use of terms such as low impact development (LID) (Department of Environmental Resources, 1999), sustainable urban drainage systems (SUDS) (CIRIA, 2000), water sensitive urban design (WSUD) (Wong, 2007), best management practices (BMPs) and alternative techniques (Fletcher et al., 2015; Mrowiec, 2006). These terms are adopted to represent actions and practices that are used for a given set of conditions to manage the quantity and improve the quality of stormwater runoff in the most cost-effective manner. It means, that new approach should slow down the rate of flow through various controls as close to the source as possible, thereby promoting infiltration, the collection of solids through sedimentation, the uptake of nutrients and the reduction of contaminants through vegetation uptake and bacterial action (Scholz, 2006; Zawilski et al., 2014). In the beginning SUDS were implemented as single purpose facilities however this has now evolved into more integrated systems which serve a variety of purposes, including habitat and amenity enhancement (Fletcher et al., 2013). They are therefore designed with three objectives in mind (Backstrom et. al 2002):

- to control the quantity and influence timing of runoff from a development;
- to improve the quality of the runoff;
- to enhance the nature conservation, landscape and amenity value of the site and its surroundings.

For newly developed sites the possibilities to integrate of drainage facilities to the landscape and buildings is significantly easier than for existing sites. On the planning stage some quantity impacts can be reduced through minimal disturbance techniques that include the following:

- reduce paving and compaction of permeable soils,
- siting building layout, clearing and grading to avoid removal of existing trees,
- minimizing imperviousness by reducing the total area of paved surfaces,
- disconnecting as much impervious area as possible to reduce runoff,
- maintaining existing topography and associated drainage flow paths,
- if possible lengthen flow paths, flatten site and lot slopes, maximize overland sheet flow and use of open swale systems,
- minimizing the influence of the equipment construction and material storage areas during building phase.

Sustainable approach to the stormwater management have the general advantage over conventional systems (Butler and Davies, 2000):

- a greater ability to attenuate flows and re-establish flow conditions similar to those prior to development,
- the pollutants remain distributed across the catchment rather than accumulating at single location,
- lower capital cost and, in many instances, maintenance costs,
- provision of aesthetically please landscaping features within urban catchment.

The concept of sustainable development of urban drainage systems

Water Sensitive Urban Design (WSUD) is a much more global term used to describe an approach to planning and designing towns and cities through integrated and sustainable approaches to water management. It looks at the water cycle as a whole and how urban environments can best be developed to bring about healthy ecosystems by integrating the whole water cycle. General concept is as follows: urban water should be managed as close to the source as possible to restore small-scale water systems. WSUD can improve public awareness for stormwater by making stormwater visible in the design of public and private open spaces in the city. Decentralised stormwater management measures can improve not only the visual aesthetics but also the quality of life in a city. Green spaces and water are key factors for the quality of life in cities. Design of stormwater solutions should be adapted to the surrounding area (buildings, infrastructure, landscapes). It is therefore always necessary to consider conditions at the site, including topography, ground permeability, groundwater table levels, and water quality among other issues. The final choice is dependent on the primary use (infiltration, retention, usage), the available space, and the topography of the surrounding area (Hoyer et al., 2011).

The conditions for stormwater systems in cities may change in the future. Significant reason is climate changes (increased frequency of high rainfall events, more dry periods). Many researchers have reported in their studies that the expected increase in design intensities due to climate change can reach 20%-80%, depending on the region (Willems et al., 2012). Another is the effect of demographic changes (population growth or reduction). For these reasons, water sensitive techniques should be developed, like any other urban infrastructure or architectural solution, to be flexible for future conditions, such as extreme weather events or future demographic and economic situations.

It is beyond the scope of this paper to describe all technical solutions that can be used to control the water-quality aspects of urban stormwater runoff but the selected ones are primary and represent the predominant removal mechanisms: bioretention, dry wells, infiltration trenches. Design of each type of facilities require careful analysis of many factors according to general scheme showed on figure 1. For existing built-up areas specially important is to fit the proper facility to the site conditions. Some devices constrains are difficult to meet in densely areas i.e.: minimal distance of infiltration trenches from buildings is recommended to 3,0 m; minimal infiltration rate of soil for bioretention purpose is $2*10^{-6}$ m/s, minimal longitudinal slope for swale is 1% etc. The integration of these facilities into the landscape throughout the site offers more opportunities to mimic the natural hydrologic functions, and add aesthetic value. Small distributed systems offers also a major technical advantage: one or more of the systems can fail without undermining the overall integrity of the site flow control. Infiltration and retention of stormwater typically requires a large area and space in a city is often hard to come by. The best part of WSUD as a tool for stormwater management is that a wide array of solutions when appropriately designed can easily complement any recreational or natural environment.

Decentralised stormwater management measures rely heavily on maintenance and upkeep to guarantee performance. Maintenance is often not taken into account or is carelessly facilitated. Inadequate maintenance, on green roofs or bioretention ponds for example, not only affects performance but significantly detracts from the aesthetic value of the installation (Burszta-Adamiak, 2012).

Water Sensitive Urban Design integrates fields such as water management, urban planning, urban design and landscape architecture. This approach can be successfully implemented by a team consisting of civil engineers, urban planners, architects, urban designers, landscape architects and also the local authorities. Cooperation should take place as early as

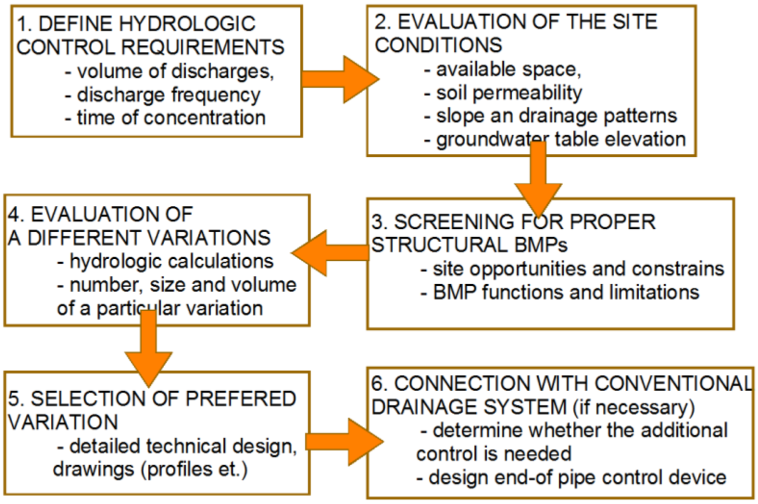

Figure 1. Scheme of selection and design infiltration/retention facility (Mrowiec, 2003)

possible in the planning and design process. The earlier cooperation takes place, the better the different demands can be coordinated and included in the final project.

Rather than technical issues, acceptance is often problem in the implementation of a WSUD concept, because it is relatively new and not fully understood by community. It is important to consider the demands of all stakeholders and involve them in the planning process. It is often necessary to involve residents, owners and users in the planning process – so acceptance and appropriate use and care of urban spaces can be sustained. The design process should be preceded to promote a better understanding of decentralised stormwater management. Exposure of examples of successful implementation can lead to broader acceptance and even generate enthusiasm for sustainable stormwater management. It is good idea to make comparison between conventional solutions and decentralized system using Life Cycle Assessement (LCA).

The most effective way to maintain clean surface waters is to eliminate the sources of pollution, not to remove pollution once it has gotten into the system. Thus, educational and institutional practices that result in behavioral changes which reduce the amount of pollutants entering to the stormwater system (i.e. disconnect illicit wastewater connections, control accidental spills, and enforce violations of ordinances designed to water protection) are crucial during implementation of decentralized systems. Education of the public to modify behaviour that contributes to prevent pollutant deposition on urban landscapes and its uncontrolled transport to receiving waters. The changes in activities, behaviours and attitudes of people are very difficult to achieve and require sustained efforts on the part of those attempting to implement them (Debo and Reese, 2002). The main advantage is that nonstructural practices are less expensive than structural ones, although it's very hard to measure their efficiency.

SUDS implementation – case study

Augustenborg is a highly populated inner-city suburb in Malmö, it covers over 32 hectares and was built in the 1950s. The buildings are 3÷4 stories high, situated close together, as well as 1÷2 stories. There are about 1900 apartments in the area, as well as various industrial buildings. Stormwater from the area was originally drained via a combined sewer system (pipe diameters between 225 and 750 mm). During intensive rain storms, flooding in basements and garages occurred causing material damage. In an effort to solve those problems, it was proposed that Augustenborg will be disconnected from the existing combined sewer and drained by means of an open stormwater system.

The new drainage system consists of a complex arrangement of different facilities and has been operational since 2002. Stormwater is conveyed through a complex arrangement of green-roofs, swales, shallow channels (400÷700 mm deep), ponds and wetlands. The modeling research made by Villareal (2004) found that the system is likely to be able to handle runoff volumes locally for all the return periods (up to 10 years) considered, as well as considerably attenuate peak flows. Results showed that the total annual runoff volume is reduced by about 25% compared to the conventional system.

The approach used in the city of Malmö, illustrates cooperation among stormwater management agencies (Stahre, 2006). Previously, stormwater was the responsibility of the city's drainage department. However, this new approach leads to more interaction among the different city's departments. A policy was written for the concept of sustainable development of stormwater systems. The policy's main objective is to obtain a common reference point and consensus among the city's departments on the concept of sustainable stormwater management. The policy document is kept fairly general and does not include precise design guidelines for technical solutions (technical issues are left to the engineers). Two departments – Water and Wastewater and Park and City Environment – are the most involved in the implementation of the concept of WSUD. The experts from each department work together on water facilities – new devices are planned, designed, and financed jointly.

Figure 2. Stormwater system in Augustenborg: a) wet pond located between block of flats, b) dry retention basin, c) open natural channel (Photos: M. Mrowiec)

The development of a typical stormwater project in the city of Malmö has the following steps:

- general conception – common vision must be actively developed by departments,
- planning – the vision elaborated must be involved in the planning process as early as possible,
- additional partners – developers are typically interested in being involved,
- public promotion – public outreach is important for acceptance,
- Design stage – design process is based on the multiple purposes defined in previous stages (documentation must fulfill all legal requirements),
- financing – costs are shared among the involved parties according to their benefits (analysis contains investment and operational phases),
- realization – before construction phase, the maintenance responsibilities must be decided.

The experience of Malmö shows that the difficulties due to sustainable development of urban drainage systems are not technical. The major problems arising in the implementation are more institutional and are connected with cooperation among different departments of the city administration. It took several years for the City of Malmö to break the barriers among the departments to plan and implement jointly owned and operated water facilities. In addition, the new and difficult element in sustainable stormwater projects is the integrated approach where hydraulic criteria are combined with ecology, biology, and aesthetics considerations.

Conclusions

Sustainable development concept applied to urban drainage systems offers flow control and pollution removal, as well as secondary benefits of water quality and ecology improvements. Moreover, in being effective in terms of performance, they also can be cost-effective in terms of investment and maintenance, when compared with conventional systems. Sustainable development of drainage infrastructure means a mix of both high and low technical solutions to find a balance between investment cost and performance efficiency.

The example of Augustusborg shows that decentralized stormwater system can be implemented even in existing districts, developed over 50 years ago. For newly developed areas it should be treated as standard (not as *alternative*) approach to drainage systems. Practically it requires:

a) cooperation and engagement of many institutions (departments) and
b) information campaign aimed to local community, to be successful project.

Even if source control measures for urban drainage are gaining popularity in many countries, there are still many uncertainties attached to them in a widespread use. The perceived research needs are: performance indicators to qualify the sustainability of such systems in socio-economic, environmental and technical terms and development of more general efficiency criteria for source controls evaluation.

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