DOI: 10.1515/jwld-2015-0007

JOURNAL OF WATER AND LAND DEVELOPMENT
2015, No. 25 (IV–VI): 3–12
PL ISSN 1429–7426
Available (PDF): http://www.itp.edu.pl/wydawnictwo/journal; http://www.degruyter.com/view/j/jwld

Received 01.06.2015
Reviewed 10.06.2015
Accepted 11.06.2015

A – study design
B – data collection
C – statistical analysis
D – data interpretation
E – manuscript preparation
F – literature search

Sustainable urban development through an application of green infrastructure in district scale – a case study of Wrocław (Poland)

Martyna SURMA [ABCDEF]

Wrocław University of Environmental and Life Sciences, Faculty of Environmental Engineering and Geodesy, Plac Grunwaldzki 24a, 50-365 Wrocław, Poland; e-mail: martyna.s@wp.pl

For citation: Surma M. 2015. Sustainable urban development through an application of green infrastructure in district scale – a case study of Wrocław (Poland). Journal of Water and Land Development. No. 25 p. 3–12

Abstract

The main goal of this article is to investigate sustainable urban development of the Central European city (Wrocław/Poland) through an environmental engineering application of SUDS (Sustainable Urban Drainage Systems) measures to managing stormwater in city sections with various land use in the same watershed area (the Ślęża River Valley). The author presents a study made in three different parts of the city (single housing district – Oporów, multihousing district – Nowy Dwór, public service district – Stadion), which were constructed in different historical periods. The analyses were supported by city masterplan, GIS software (Quantum GIS 1.7.4) and calculations made according to up-to-date specific regulations. They demonstrate the current sustainable stormwater management scenarios for areas of different land use, historical periods and function in the city. The proposed research method aims to compare sustainable urban development of the new urban district with the quarters, which had been built before the term "sustainability" became common in water and land development practice. The conducted study can be practically used as a supportive tool for urban planning authorities in Poland. The paper investigates a novel in the Polish realities method of assessment sustainability of the area through green infrastructure application in district scale.

Key words: *green infrastructure, stormwater management, sustainable urban development*

INTRODUCTION

The implementation of green infrastructure in smaller scale than the city (district or neighbourhood scale) seems to be necessary to understand the importance of stormwater management for contemporary urban areas. Moreover, this approach is important for sustainability reasons in the broader context of social dimensions, as it demands common understanding and cooperation between local authorities and citizens, who own plots. The green infrastructure applications in district scale are presented as the patch – corridor model, referring to the landscape ecology paradigm, though in smaller scale and supported by environmental engineering solutions. The most appropriate for the smallest urban scale are semi-natural sustainable urban drainage systems (SUDS), which provide stormwater management by the use of green areas[1)] and environmentally friendly materials (e.g. permeable asphalt or concrete) [FERGUSON 2005]. In this field, there are thousands of papers on modern stormwater management (often referred to under such headings as LID – Low Impact Development, GI – Green Infrastructure, WSUD – Water Sensitive Urban

[1)] Source: www.ciria.org (21 April 2015).

Design) as they are gaining popularity nowadays increasing sustainability in a broader context [DIETZ 2007; GILL *et al*., 2007; ARGUE, BARTON 2007]. Even street trees can play an important role for contemporary stormwater management systems, if they are planted in the special high tech construction, which retains stormwater to let the plants grow [US EPA 2013]. The comprehensive implementation of 'repair strategies' is possible in every place, where we don't have possibilities to build a new urban structure from the start (e.g. Ørestad – Copenhagen/Denmark). The eco modernization of grey infrastructure seems to be not only more pragmatic solution from economic point of view, but also – easier to implement in the Polish realities. Currently, there are not enough regulations in Poland, which could guarantee the implementation of green infrastructure in the scale of a local plan. The implementation of the EU Floods Directive[2] in the European countries initiated integrative management of flood risk, including actions based on coexistence with water (e.g. green infrastructure investments). The conventional sewer systems (grey infrastructure) prevent the stomwater from infiltrating to the ground, which consequently increases the flood risk [KESSLER 2011]. In the United States, the main legal motivation to invest in green infrastructure is based on the Clean Water Act (CWA)[3] – the federal document outlining quality standards of surface water in the whole country. The American Environmental Protection Agency (EPA) refers to this document during implementation of the green infrastructure programs [City of New York 2010]. Moreover, the same Agency states, that uncontrolled urbanization processes increase runoff and the negative impact on water quality, which additionally emphasizes the influence of planning decisions for sustainable stormwater management from the very beginning [US EPA 2006]. Some public authorities go even further and include the green infrastructure elements as an integral part of the building construction [Public Utilities Board 2009]. This study aims to compare the typical urban forms in the city of Wrocław (Poland): private housing, semi-public housing and public open space. Three different periods of development present different scenarios of stormwater management on these areas. The main research questions are: can we manage the stormwater according to sustainability reasons now? does the planning approach differ in that context after joining the EU in 2004? how can we increase the effectiveness of stormwater management by green infrastructure?

The masterplan of the Polish city is an obligatory document for the whole city area, whilst the local plan is necessary only for the chosen districts. The only one law regulation for green areas in the district scale refers to so-called biologically-active areas[4]. It is mandatory for investors to plan 25% (general index) of the plot with the green space. Although, there is a lack of grading system for these areas, which means, that the environmental value is the same for the lawn and urban forestry on the plot of the same size. According to the current legislation, the ecosystem value is not taken into consideration in any sense. Moreover, there is no connection between green areas and sustainable stormwater management on the specific areas, which would help to determine the value for the index more specifically in the future. There is also a lack of information regarding green roofs (no diversification between intensive, extensive type etc.). In spite of a growing interest in green roofs, the data related to their retention capacity in Polish conditions is still insufficient [BURSZTA-ADAMIAK 2012]. More specific grading system would be useful to achieve a better stormwater management of the areas, as well as to improve environmental services in a local scale. Also the district plans should be integrated with the general GI plans for the whole city. To assess the current potential of sustainable stormwater management in Wrocław, the author conducted the research on three chosen districts.

STUDY AREA

Three study areas were selected to perform simulation of stormwater management with the possibilities of eco modernization of the grey infrastructure. The districts represent urban structures typical for the whole city area (Fig. 1).

The criteria of selecting the study areas:

- The common feature of the study areas is their location in the same watershed (the Ślęża River).
- Analyzed districts represent different functions (according to the classification from the masterplan):
  a) single family housing district (Oporów);
  b) multifamily housing district (Nowy Dwór);
  c) public services (Stadion).
- Analyzed districts represent different types of urban space:
  a) private space;
  b) semi-public space;
  c) public space.
- Present urban structure of the analyzed districts were shaped in different historical periods:
  a) beginning of the 20th century;
  b) end of the 1970s;
  c) beginning of the 21st century.
- Analyzed areas represent typical urban structures for the historical periods of time.

[2] Directive 2007/60/EC on the assessment and management of flood risks entered into force on 26 November 2007.

[3] Federal Water Pollution Control Act Amendments of 1972; An Act to amend the Federal Water Pollution Control Act (18 October 1972).

[4] Acc. to the Regulation of the Ministry of Infrastructure on the technical requirements to be met by buildings and their location (12 April 2002), biologically-active areas include the ground area which enables the natural vegetation, 50% of the green roofs (but not less than 10 m^2) and surface water.

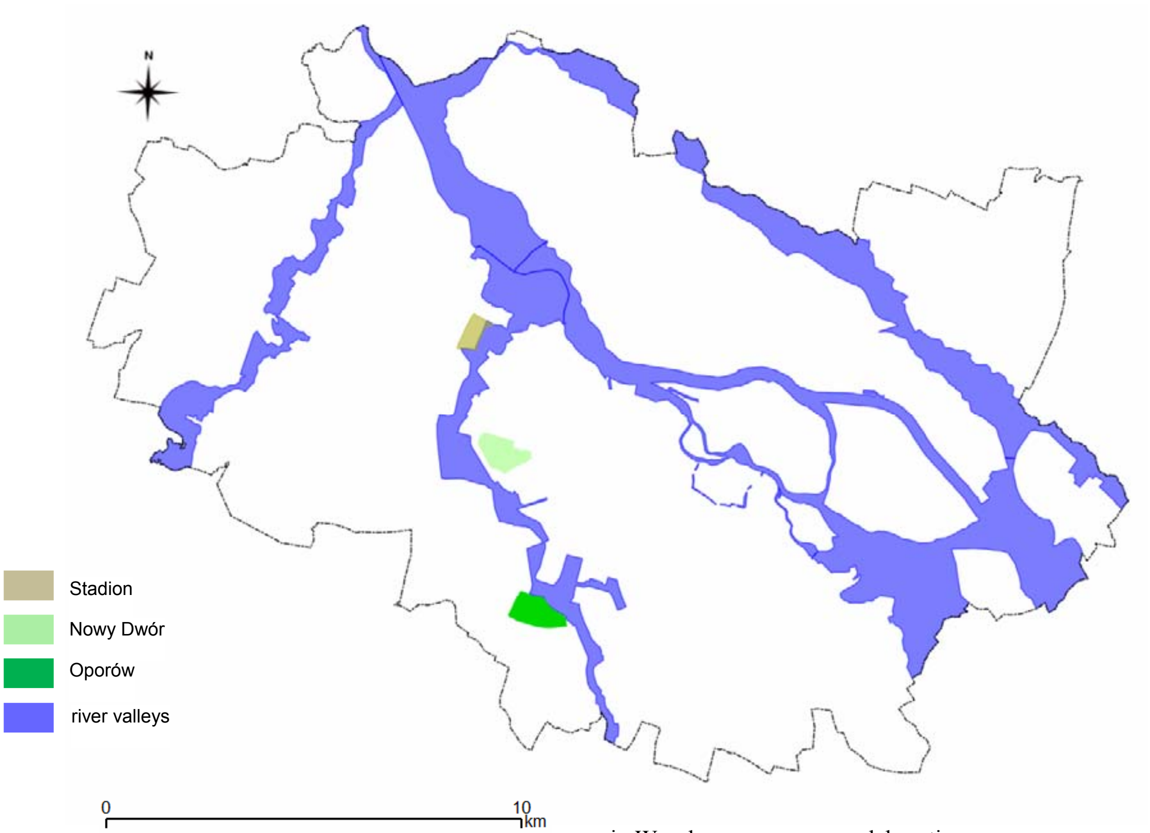

Fig. 1. Location of the research areas in Wrocław; source: own elaboration

MATERIALS AND METHODS

The digitalization of certain districts with the software Quantum GIS (1.7.4) and updated online service 'Wrocław Spatial Information System' was the first step to perform the simulation of stormwater management. The classification covered all the impervious surfaces (roads, rooftops). All permeable areas (vegetated areas, permeable pavements, green roofs) were selected as the potential green infrastructure units. In further stage of the study, the impervious area was calculated and reduced by implementation of green infrastructure. The reduced areas were calculated based on the ratio of runoff index for a given type of surface and its area (according to the values of runoff indices based on Polish standards regulated by the law[5]). The indices are commonly used in Polish practice for calculating the amount of stormwater needed to be drained from the area of investment[6] (Tab. 1).

[5] PN-92/B-01707. The sewer systems. Requirements in design.

[6] Technical conditions to drain rainwater from the area of investment refer to the following regulations (in Polish): Ustawa Prawo budowlane z dnia 7 lipca 1994 r. tekst jednolity Dz.U. 2006 nr 156 poz. 1118 z późniejszymi zmianami; Ustawa Prawo wodne z dnia 18 lipca 2001 r. tekst jednolity Dz.U. 2005 nr 239 poz. 2019 z późniejszymi zmianami; Ustawa z dnia 14 czerwca 1960 r. Kodeks Postępowania Administracyjnego (tekst jednolity Dz.U. 2000 nr 98 poz. 1071 z późniejszymi zmianami).

Table 1. Runoff indices according to the Polish norm

Types of surfaces	Runoff index
The roof's slope >15	1.00
The roof's slope <15	0.80
Roof covered with gravel	0.50
Garden on the rooftop	0.30
Impervious surfaces	0.90
Impervious pavements	0.60
Permeable pavements, alleys, backyards	0.50
Playgrounds, sport fields	0.25
Gardens	0.10–0.15
Parks	0.05

Source: own elaboration according to PN-92/B-01707.

Moreover, to evaluate the performance of extensive green roofs, the runoff index according to the American regulations was applied [New York City Department of Environmental Protection, New York City Department of Buildings 2012].

RESULTS

THE SINGLE FAMILY HOUSING DISTRICT

The settlement area Oporów is densely covered by low-rise buildings with sloping rooftops (Fig. 2). There is also a quite regular road network and some single squares. The green areas were calculated without differentiation into private and semi-public space. The impervious pathways on private lots were not

Fig. 2. The types of surfaces; source: own elaboration

taken into account due to their minor contribution to the general hydrological balance in the district scale (low runoff rate).

Different types of surfaces were classified to get detailed characteristic of the permeability of the area (impervious surfaces versus permeable areas – green infrastructure units). The characteristics of the area:

– impervious surfaces: 16.2 ha (19.8% of the area);
– permeable surfaces (green infrastructure units): 65.6 ha (80.2% of the area).

The results are presented below (Tab. 2).

Table 2. Drained area (ha) – single family housing district – now

Types of surfaces	Runoff index x area ha
Rooftops (sloping >15)	10.00
Rooftops (sloping <15)	–
Roads	5.04
Pavements	–
Parking lots, plazas	0.54
Sport fields	0.03
Green areas	6.55
Total	**22.16**

Source: own elaboration according to PN-92/B-01707.

The runoff from:

– impervious surfaces: delivers 70.3% of the total stormwater to conventional sewer system as runoff;
– permeable surfaces (green infrastructure units): delivers 29.7% of the total stormwater to conventional sewer system as runoff.

Conclusion: permeable surfaces in the analyzed area (four times larger than impervious surface) generates around two and a half times less runoff. The runoff can be even more reduced when we apply some of the green infrastructure elements on private plots (rain barrels, rain gardens) and manage stormwater on site. Still, large enough green area (gardens with trees) provides the effective infiltration, transpiration and evaporation. A bit different situation is presented in multifamily housing area in the next chapter.

THE MULTIFAMILY HOUSING DISTRICT

The area of Nowy Dwór is generally covered by high-rise buildings with flat rooftops. There is also a minor part of low-rise buildings with sloping rooftops (the eastern part of settlement) (Fig. 3).

Different types of surfaces were classified to get detailed characteristic of the permeability of the area (impervious surfaces versus permeable areas – green infrastructure units).

The characteristics of the area:

– impervious surface: 27.9 ha (35.5% of the area);
– permeable surface (green infrastructure units): 50.6 ha (64.5% of the area).

The results are presented below (Tab. 3).

Scenario I – now

The runoff from:

– impervious surface: delivers 49.8% of the total stormwater to conventional sewer system as runoff;
– permeable surface (green infrastructure units): delivers 50.2% of the total stormwater to conventional sewer system as runoff.

Fig. 3. The types of surfaces – multifamily housing district; source: own elaboration

Table 3. Drained area (ha) – multifamily housing district – scenario I – now

Types of surfaces	Runoff index x area ha
Rooftops (sloping > 15)	1.80
Rooftops (sloping < 15)	**8.64**
Roads	8.82
Pavements	1.80
Parking lots	2.25
Sport fields	0.35
Green areas	24.6
Total	**48.26**

Source: own elaboration according to PN-92/B-01707.

Table 4. Drained area (ha) – multifamily housing district – scenario II – the alternative option

Types of surfaces	Runoff index x area ha
Rooftops (sloping >15)	1.80
Gardens on the rooftops	**3.24**
Roads	8.82
Pavements	1.80
Parking lots	2.25
Sport fields	0.35
Green areas	24.6
Total	**42.86**

Source: own elaboration according to PN-92/B-01707.

Conclusion: permeable surface on the analyzed area (two times greater than impervious surface) generates similar amount of runoff. The runoff can be even more reduced, when we apply some of the green infrastructure elements on the area (green roofs, rain gardens) and effectively manage stormwater on site. Replacement of the conventional flat rooftops (on the area) with the green roofs is presented as scenario II – the alternative option and scenario III.

Scenario II – the alternative option – gardens on the rooftops

The characteristics of the area:

- impervious surface: 38.6 ha (21.7% of the area);
- permeable surface (green infrastructure units): 61.4 ha (78.3% of the area).

The results are presented below (Tab. 4).

The runoff from:

- impervious surface: delivers 34.2% of the total stormwater to conventional sewer system as runoff;
- permeable surface (green infrastructure units): delivers 65.8% of the total stormwater to conventional sewer system as runoff.

Conclusion: eco modernization (implementation of the green roofs) in the analyzed area can reduce the amount of runoff in conventional sewer system. Still there is a need of verification of this data according to the American runoff index for the extensive type of green roof, which is proposed for that kind of roof construction. The term 'green roof' used in the Polish index regulations seems to be too general. Scenario III (according to the American regulations) is presented below as the present stage (A) (Tab. 5) and the alternative option (B) (Tab. 6). To ensure comparability of results (A and B), the index criteria come from the same norm.

Table 5. Drained area (ha) – multifamily housing district – scenario III A – now (according to the American regulation)

Types of surfaces	Runoff index x area ha
Rooftops (sloping > 15)	1.71
Rooftops (sloping < 15)	**10.26**
Roads	8.33
Pavements	2.55
Parking lots	2.13
Sport fields	0.98
Green areas	9.84
Total	**35.80**

Source: own elaboration according to PN-92/B-01707.

Table 6. Drained area (ha) – multifamily housing district – scenario III B – the alternative option (according to the American regulation)

Types of surfaces	Runoff index x area ha
Rooftops (sloping >15)	1.71
Green roof – minimum 10 cm of vegetation layer	**7.56**
Roads	8.33
Pavements	2.55
Parking lots	2.13
Sport fields	0.98
Green areas	9.84
Total	**10.82**

Source: own elaboration according to PN-92/B-01707.

Scenario III A – now (according to the American regulations)

The runoff from:

– impervious surface: delivers 69.8% of the total stormwater to conventional sewer system as runoff;
– permeable surface (green infrastructure units): delivers 30.2% of the total stormwater to conventional sewer system as runoff.

Scenario III B – the alternative option (according to the American regulation)

The runoff from:

– impervious surface: delivers 44.5% of the total stormwater to conventional sewer system as runoff;
– permeable surface (green infrastructure units): delivers 55.5% of the total stormwater to conventional sewer system as runoff.

Conclusion: eco modernization (implementation of the extensive green roofs) on the analyzed area can reduce the amount of runoff in conventional sewer system. The runoff can be even more reduced, when we apply some of the green infrastructure elements in the area (rain gardens) and effectively manage stormwater on site. Due to the fact, that the area is still in the construction process, there are possibilities to design its stormwater management in a more sustainable way from the beginning.

THE PUBLIC SERVICE DISTRICT

During data collection for the public service district, its construction phase and planning decisions haven't been completed yet. The author based the research on the existing phase of development, considering the area of undeveloped land (Fig. 4).

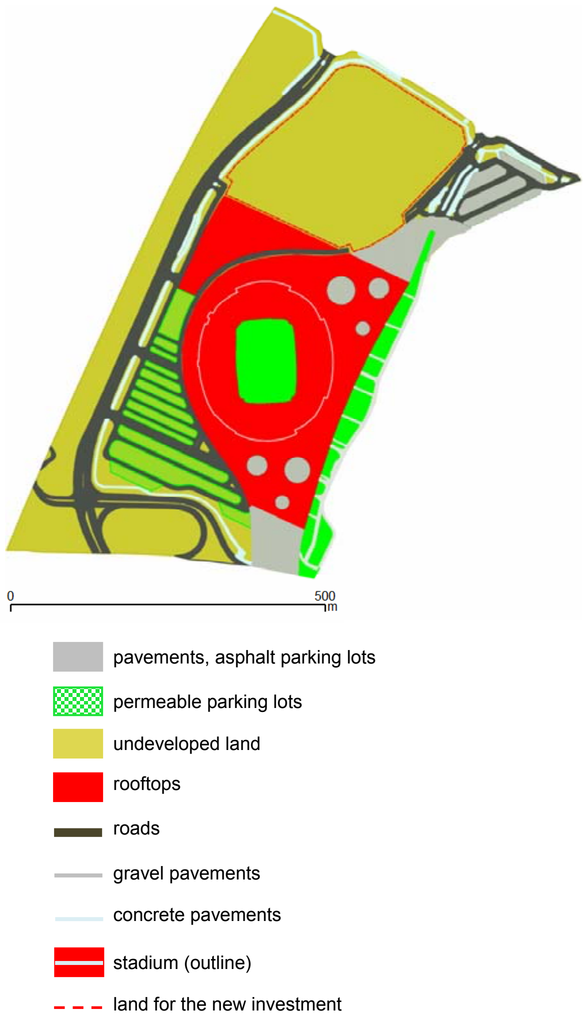

Fig. 4. The types of surfaces – public service area; source: own elaboration

Different types of surfaces were classified to get detailed characteristic of the permeability of the area (impervious surfaces versus permeable areas – green infrastructure units).

The characteristics of the area:

– impervious surface: 17.6 ha (47.5% of the area);
– permeable surface (green infrastructure units): 19.5 ha (52.5% of the area).

The results are presented below (Tab. 7).

Table 7. Drained area (ha) – public service district – scenario I – now

Types of surfaces	Runoff index x area ha
Rooftops (sloping >15)	–
Rooftops (sloping <15)	7.28
Roads	4.77
Gravel pavements	0.20
Concrete pavements	0.48
Asphalt pavements	0.84
Asphalt parking lots	0.90
Permeable parking lots	0.95
Sport fields	0.18
Green areas	0.60
Undeveloped land	**7.65**
Total	**23.85**

Source: own elaboration according to PN-92/B-01707.

Scenario I – now

The runoff from:

– impervious surface: delivers 65.5% of the total stormwater to conventional sewer system as runoff;

– permeable surface (green infrastructure units): delivers 39.5% of the total stormwater to conventional sewer system as runoff.

Conclusion: in spite of comparable size of permeable and impervious surfaces on the analyzed area, the larger amount of runoff is produced by impervious surface. The scenario II presents the same situation, including the planned built up area (Tab. 8).

Table 8. Drained area (ha) – public service area – scenario II

Types of surfaces	Runoff index x area ha
Rooftops (sloping >15)	–
Rooftops (sloping <15)	7.28
Roads	4.77
Gravel pavements	0.20
Concrete pavements	0.48
Asphalt pavements	0.84
Asphalt parking lots	0.90
Permeable parking lots	0.95
Sport fields	0.18
Green areas	0.60
New buildings	**12.24**
Total	**28.44**

Source: own elaboration according to PN-92/B-01707.

Scenario II – planned by the city authorities: 6.6 ha of undeveloped land = built up area

The characteristics of the area:

– impervious surface: 24.2 ha (65.2% of the area);

– permeable surface (green infrastructure units): 12.9 ha (34.8% of the area).

The runoff from:

– impervious surface: delivers 76.1% of the total stormwater to conventional sewer system as runoff;

– permeable surface (green infrastructure units): delivers 23.9% of the total stormwater to conventional sewer system as runoff.

Conclusion: new buildings increase the runoff in the analyzed area (compared to pre-development stage). The scenario III presents the same situation, including green roof on new buildings (Tab. 9).

Table 9. Drained area (ha) – public service district – scenario III

Types of surfaces	Runoff index x area ha
Rooftops (sloping >15)	–
Rooftops (sloping <15)	7.28
Roads	4.77
Gravel pavements	0.20
Concrete pavements	0.48
Asphalt pavements	0.84
Asphalt parking lots	0.90
Permeable parking lots	0.95
Sport fields	0.18
Green areas	0.60
Green roof	**4.59**
Total	**20.79**

Source: own elaboration according to PN-92/B-01707.

Scenario III – alternative: 6.6 ha of undeveloped land = buildings with green roof

The characteristics of the area:

– impervious surface: 17.6 ha (47.4% of the area);

– permeable surface (green infrastructure units): 19.5 ha (52.6% of the area).

The runoff from:

– impervious surface: delivers 64% of the total stormwater to conventional sewer system as runoff;

– permeable surface (green infrastructure units): delivers 36% of the total stormwater to conventional sewer system as runoff.

Conclusion: new buildings with green roof decrease runoff in the analyzed area (compared to pre-development stage), adding extra benefits in the context of sustainable urban development. Scenario IV presents the location of a park area instead of the planned new building (Tab. 10).

Table 10. Drained area (ha) – public service district – scenario IV

Types of surfaces	Runoff index x area ha
Rooftops (sloping >15)	–
Rooftops (sloping <15)	7.28
Roads	4.77
Gravel pavements	0.20
Concrete pavements	0.48
Asphalt pavements	0.84
Asphalt parking lots	0.90
Permeable parking lots	0.95
Sport fields	0.18
Green areas	0.60
Park	**0.77**
Total	**16.97**

Source: own elaboration according to PN-92/B-01707.

Scenario IV – alternative: 6.6 ha of undeveloped land = park

The characteristics of the area:

- impervious surface: 17.6 ha (47.4% of the area);
- permeable surface (green infrastructure units): 19.5 ha (52.6% of the area).

The runoff from:

- impervious surface: delivers 69% of the total stormwater to conventional sewer system as runoff;
- permeable surface (green infrastructure units): delivers 31% of the total stormwater to conventional sewer system as runoff.

Conclusion: park area decreases runoff in the analyzed area (compared to buildings with green roof). This option is most effective in the context of stormwater management in this area.

THE PUBLIC SERVICE DISTRICT – PERMEABILITY OF THE AREA ACCORDING TO DIFFERENT SCENARIOS

Scenario I – now

The characteristics of the area:

- impervious surface: 17.6 ha (47.5% of the area);
- permeable surface (green infrastructure units): 19.5 ha (52.5% of the area).

Total impervious area = 47%

Effective impervious area = 0%

Conclusion: the current construction phase of the area enables proper permeability due to the fact, that the development hasn't been finished yet.

Scenario II – planned by the city authorities: 6.6 ha of undeveloped land = built up area

The characteristics of the area:

- impervious surface: 24.2 ha (65.2% of the area);
- permeable surface (green infrastructure units): 12.9 ha (34.8% of the area).

Total impervious area = 65%.

Effective impervious area = 30%.

Conclusion: planned buildings will increase the effective impervious area by 30% (compared to pre-development stage).

Scenario III – alternative: 6.6 ha of undeveloped land = buildings with green roof

The characteristics of the area:

- impervious surface: 17.6 ha (47.4% of the area);
- permeable surface (green infrastructure units): 19.5 ha (52.6% of the area).

Total impervious area = 47%.

Effective impervious area = 12%.

Conclusion: planned buildings with green roofs will decrease the effective impervious area by around 18% (compared to buildings without green roof).

Scenario IV – alternative: 6.6 ha of undeveloped land = park

The characteristics of the area:

- impervious surface: 19.5 ha (52.6% of the area);
- permeable surface (green infrastructure units): 17.6 ha (47.4% of the area).

Conclusion: park area will keep the effective impervious area on the proper level in the context of stormwater management.

DISCUSSION

- The multifamily housing district compared to the single family district is covered by about two times larger network of roads, despite of similar study areas; this is the result of irregular built up area, which further causes complexity of a road infrastructure (the amount of runoff is consequently two times bigger); it is advisable to simplify the geometric structure of new settlements (which will limit the development of grey infrastructure) or use permeable surfaces of new technologies (permeable asphalt or concrete);
- The multifamily district compared to the single family district is covered by about 30% bigger area of rooftops; nevertheless, the amount of generated runoff is similar for both settlements; this is the result of different type of rooftops (flat and sloping); flat rooftops present a broad spectrum of possibilities for eco modernization in the future (e.g. green roof, blue roof, white roof), which increases sustainability (e.g. better water quality, reduced effect of urban heat island, reduced runoff, urban agriculture – ecological food, social aspects);
- The multifamily housing district compared to the single family district contains about four times bigger area of parking lots; the alternative for this kind of surface may be permeable materials (e.g. gravel) or subsurface drainage systems, which significantly reduce runoff;
- The multifamily housing district compared to the single family district is covered by about two times smaller area of green space; the runoff from this area is about four times larger for multifamily district due to the fact, that the backyards have a higher runoff index than gardens; it means that the type of green space should be also taken into consideration during the planning stage of a new investment;
- The infrastructure not suitable for heavy car traffic (e.g. pavements) should be permeable wherever possible (to decrease the runoff index);
- The new investment on the undeveloped land may reduce runoff only when intensive green roof is applied on the building; the runoff index will be lower than that for undeveloped land cover;
- Permeable area should be at least 50% of the total area to be able to manage 2.5 cm of rainfall in 24 hours period, which further results in 90% of stormwater maintained on site [CONDON 2010]; according to the above rule and the results of the research performed, the following relationship can be applied:

$$\frac{GI}{PA} \geq 1$$

where:

GI – green infrastructure area, localized on the ground level;

PA – permeable area.

The above relationship states, that total permeable area is smaller or equal to 50% of the land and effective permeable area equals 0% (ideal value). The optimum value for total permeable area is 10% of the land cover, which means that at least 45% of the area should be a permeable layer being able to maintain the stormwater also from the surroundings (this layer should be localized on the ground). The above relationship approved green roof as an alternative option for conventional rooftop, but not as an alternative for a green area localized on the ground level.

CONCLUSION

Performed study demonstrated, that 'sustainability' practices in Poland don't necessarily belong to the current trends in urban planning. That fact was especially visible in stormwater management simulations in the chosen areas of Wrocław. New investments sometimes offer worse runoff situation then the districts dated to the previous century. The main reason of that could be a lack of relevant legal regulations, which usually guarantee appropriate level of urban planning standards.

An enormous popularity of sustainable stormwater practices around the world is still not that important in Poland. Green infrastructure, recommended for implementation by the European Commission, constantly remains in our country a powerless definition, without any legislative strength. Especially a lack of significant planning obligations at a district level excludes its common practice.

The research conducted in the three chosen areas along the Ślęża River in Wrocław demonstrated potential for sustainable stormwater management through green infrastructure elements. Moreover, it indicated the necessity of reduction of excessive expansion of impervious infrastructure responsible for a large amount of runoff in the watershed of the Ślęża River. This was especially visible in the settlement from the 1970s. The lack of compact/regular development increases the network of transport infrastructure. The large number of flat rooftops enables the eco modernization in the future (e.g. extensive green roofs). Also, there is a minor application of permeable surfaces, even in the new district.

The important effect of performed analyses could be the index of "permeable area localized on the ground" – based on the American knowledge in this field – which should be at least 45% of the total area. This kind of assumption could be used for the city's climate adaptation plan, which is usually integrated with sustainable stormwater management (Fig. 5).

To sum up, there is a broad spectrum of environmentally-friendly actions to increase sustainability of urban environment. The green infrastructure could be one of them.

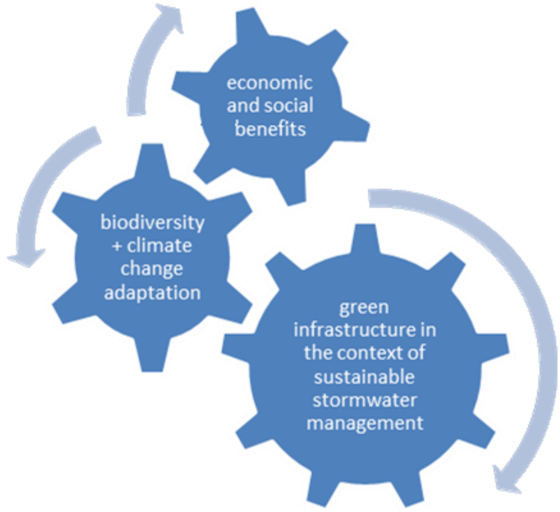

Fig. 5. Process of generating benefits for the city in terms of American concept of green infrastructure; source: own elaboration

REFERENCES

ARGUE J.R., BARTON A.B. 2007. A review of the application of water sensitive urban design (WSUD) to residential development in Australia. Australian Journal of Water Resources. Vol. 11. No. 1 p. 31–40.

BURSZTA-ADAMIAK E. 2012. Analysis of the retention capacity of green roofs. Journal of Water and Land Development. No. 16 p. 3–9.

City of New York. 2010. NYC green infrastructure plan. New York.

CONDON P. 2010. Seven rules for sustainable communities: design strategies for the postcarbon world. Washington. Island Press.

DIETZ M.E. 2007. Low impact development practices: a review of current research and recommendations for future directions. Water Air Soil Pollution. Vol. 186. Iss. 1–4 p. 351–363.

FERGUSON B.K. 2005. Porous pavements: Integrative studies in water management and land development. New York. Taylor and Francis. ISBN 978-0849326707 pp. 600.

GILL S. E., HANDLEY J. F., ENNOS A. R., PAULEIT S. 2007. Adapting cities for climate change: the role of the green infrastructure. Built Environment. Vol. 33. No. 1 p. 115–133.

KESSLER R. 2011. Stormwater strategies. Cities prepare aging infrastructure for climate change. Environmental Health Perspectives. Vol. 119. Iss. 12 p. 514–519.

New York City Department of Environmental Protection 2012. Guidelines for the design and construction of stormwater management systems. New York.

PN-92/B-01707. Instalacje kanalizacyjne. Wymagania w projektowaniu [The sewer systems. Requirements in design].

Public Utilities Board 2009. Active, beautiful, clean waters. Design guidelines. Singapore.

US EPA 2006. Protecting water resources with higher-density development. Washington, DC.

US EPA 2013. Stormwater to street trees. Engineering urban forests for stromwater management. Washington, DC.

Ustawa z dnia 7 lipca 1994 r. – Prawo budowlane [The Construction Law of July 7, 1994]. Tekst jednolity. Dz.U. 2006. Nr 156 poz. 1118 z późniejszymi zmianami.

Ustawa z dnia 18 lipca 2001 r. – Prawo wodne [The Water Law of July 18, 2001]. Tekst jednolity. Dz.U. 2005. Nr 239 poz. 2019 z późniejszymi zmianami.

Ustawa z dnia 14 czerwca 1960 r. Kodeks postępowania administracyjnego [The Administrative Procedure Code Act of June 14, 1960]. Tekst jednolity Dz.U. 2000. Nr 98 poz. 1071 z późniejszymi zmianami.

Martyna SURMA

Zrównoważony rozwój miasta poprzez zastosowanie zielonej infrastruktury w skali dzielnicy na przykładzie Wrocławia

STRESZCZENIE

Celem pracy była analiza procesu urbanizacyjnego Wrocławia w kontekście zrównoważonego rozwoju poprzez symulację gospodarowania wodą opadową w skali dzielnicy. Do celów badawczych wybrano trzy charakterystyczne rodzaje zabudowy miasta z różnych okresów historycznych (Oporów – zabudowa jednorodzinna, Nowy Dwór – zabudowa wielorodzinna, Stadion – teren usługowy), znajdujące się w zlewni rzeki Ślęza. W celu przeprowadzenia analiz wykonano wektoryzację obszarów za pomocą oprogramowania Quantum GIS (1.7.4) oraz aktualizowanych map Systemu Informacji Przestrzennej Wrocławia dostępnych w serwisie internetowym. Sklasyfikowano wszelkie powierzchnie nieprzepuszczalne, tj. nawierzchnie utwardzone, pokrycia dachowe. Za potencjalne składowe zielonej infrastruktury uznano natomiast powierzchnie przepuszczalne, tj. obszary wegetacyjne, nawierzchnie przepuszczalne, zielone dachy. W obliczeniach porównawczych posłużono się wartościami współczynników spływu według polskiej normy PN-92/B-0170. Dodatkowo, w ocenie zielonych dachów ekstensywnych, wykorzystano współczynnik spływu według opracowań amerykańskich. Badanie przepuszczalności wybranych trzech obszarów wzdłuż rzeki Ślęza w granicach Wrocławia wykazało duże możliwości kształtowania zrównoważonej gospodarki wodnej tych terenów poprzez zastosowanie elementów zielonej infrastruktury.

Słowa kluczowe: *gospodarka wodą opadową, zielona infrastruktura, zrównoważony rozwój miasta*