INFRASTRUKTURA I EKOLOGIA TERENÓW WIEJSKICH
INFRASTRUCTURE AND ECOLOGY OF RURAL AREAS

Nr III/1/2016, POLSKA AKADEMIA NAUK, Oddział w Krakowie, s. 801–821
Komisja Technicznej Infrastruktury Wsi

DOI: http://dx.medra.org/10.14597/infraeco.2016.3.1.059

# LOCAL FLOODING IN THE USA, EUROPE, AND POLAND – AN OVERVIEW OF STRATEGIES AND ACTIONS IN FACE OF CLIMATE CHANGE AND URBANISATION

***Elżbieta Jarosińska***
*Politechnika Krakowska*

***Summary***

Urbanisation and climate change have significant impact on disturbing water balance in catchments. Uncontrolled urban development, increased land surface sealing, and increasingly appearing heavy rainfall cause local inundations called urban flooding. Rational catchment water management necessitate that a new approach to the problem of flooding be introduced that includes the human factor. Greater emphasis should be placed on local management of rainfall water within catchment, especially in urban areas. What is more, it is of utmost importance to provide efficient legal system and co-operation of various authorities and decision-makers in terms of urban land use management.

The present article reviews different courses of actions taken in order to improve reasonable water management in the USA, Europe, and Poland in face of climate change and urbanization that cause flooding.

**Key words:** urban flooding, flash floods, impervious cover, rainfall events, urbanisation, urban runoff

## INTRODUCTION

Fresh water is an important factor that determines the survival of mankind on Earth. Its shortage or surplus may constitute a serious problem that may, at worst, result in a natural disaster event, i.e. drought or flood. The challenge that the responsible authorities should face today is to provide an answer to the question of how to manage water resources in order to satisfy the needs of people and, at the same time, to reduce the frequency of occurrence of natural disasters.

There is a long-standing history behind the occurrence of floods in many a European country as well as outside of the continent. Relevant archives contain information on flood formation, the costs of disaster recovery and prevention measures. Current flood control actions are considered in the context of flood recovery actions and are mainly focused on the protection of valleys and river beds.

However, the causes of floods are not to be sought exclusively on the side of the river's outflow. This is because there are often events of so-called urban flooding occurring in cities as the effect of rain water overflow from overloaded storm water systems (CNT 2013). It is increasingly more common for dangerous events of so-called flash flood (RCB 2013) to occur that form in a short time (less than 6 hours) as a result of one or several storm events. When the water from increased rainfall cannot be absorbed by the soil or discharged by sewage system, it floods the low-lying areas (Gupta *et al.* 1996, Geiger 1987, NOAA). According to Marchi *et al*. (2010) and Barredo (2006), 40% of the floods that occurred in Europe in years 1950-2006 were the instances of urban flash floods.

The rapidly progressing urbanisation is one of the most characteristic examples of demographic, social, and economic processes of today's world. It consists in both demographic and spatial growth, as well as the emergence of new urban centres or the transformation of villages into towns (Jałowiecki 1999).

In cities, the process of changes in land use is significant and this results in the majority of the land area becoming sealed surface. This factor constitutes additional flood hazard that so far seems to have been disregarded as a main cause of flooding by authorities deciding on flood protection measures (Kowalczak 2011). What is interesting is that the pace of urbanisation does not result from population growth. According to a report by the European Commission (CE 2012), the pace of taking up land for urbanisation and infrastructure purposes is over two-fold higher when compared to the population growth rate. To illustrate this with an example, the report refers to the fact that in years 1990-2006 the EU noted a 9% increase in the number of built-up areas (from 176 200 $km^2$ to 191 200 $km^2$) while the population increased by merely over 5% over the same time period (CE 2012). The European Environment Agency (EEA Report No 10 2006) also states that rather than from growing population, the urban development results from people's consumer-driven lifestyle changes. Discussion about flooding causes must also consider climate change (Directive 2007) that are different in terms of pace and intensity in different countries.

In view of the above, the phenomenon of flooding as such will most certainly continue. This is why, for better and wiser management of water in catchment, a new approach to flooding is becoming valuable that considers not only the meteorological and hydrological issues but also additional human factors that more and more often exacerbate the problem.

The article aims at reviewing current strategies that outline courses of actions in the USA, Europe, and Poland and proposed good practices that lead to rational water management in face of climate change and urbanisation.

## SURFACE SEALING AND RUNOFF

Urban development often takes place in an uncontrolled way (development of suburban or rural areas) at the expense of nature, agriculture, and forestry. This, in turn, has serious implications and results in soil sealing (Fig. 1) that is visible in constant laying the surface with impervious cover (i.e., tarmac or concrete) as the number of buildings, pavements, and roads including motorways increases.

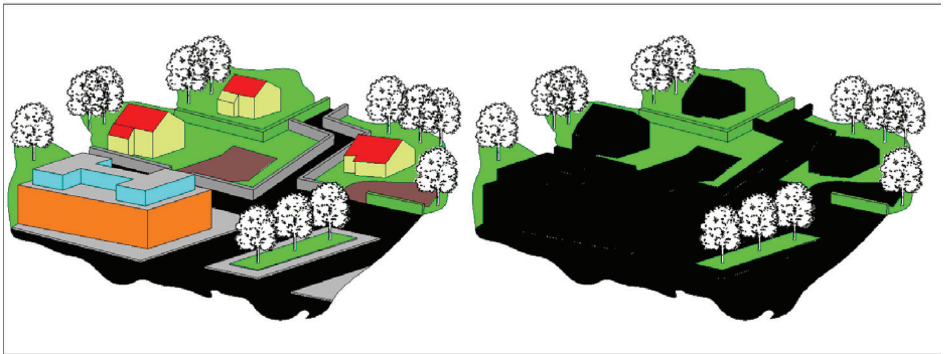

**Figure 1.** Built-up area (left) and soil sealing (right) – dark places indicate soil sealing of an area built up (modified based on: CE 2012; http://ec.europa.eu/environment/soil/pdf/guidelines/pub/soil_pl.pdf)

Soils perform important functions in the ecosystem: among others, they regulate (filter and brake) the flow of water to the aquifer thanks to which they reduce flood and drought risks. 'Healthy' soil can store up to 3750 tonnes of water per hectare or a significant amount of rainfall (up to 400 mm) (CE 2012). In other words, 1 cubic metre of porous soil can inhibit between 100 and 300 litres of water [Sachsen.de]. Sealed soil will lack in such kind of absorption capacity.

Surface sealing contributes to reducing the size of retention and infiltration (Fig. 2) which further results in shorter time of rainfall runoff from catchment and, at the same time, a significant increase in the amount of runoff (Fig. 3). While it cannot be absorbed by soil, the water uses local downslopes and travels down the roads or pavements to the closest receivers and reaches the storm water drainage system (Bajkiewicz-Grabowska 2013). In many cases the sewers then become overloaded (the capacity of the drainage system becomes exceeded) and causes local flooding or inundations.

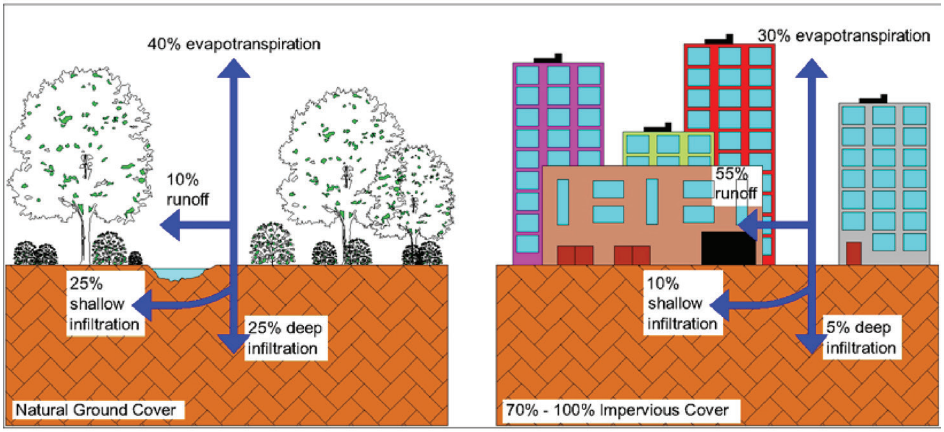


**Figure 2.**The impact of sealed surface on runoff in catchment (modified based on: EPA 2003; http://www3.epa.gov/npdes/pubs/nps_urban-facts_final.pdf)

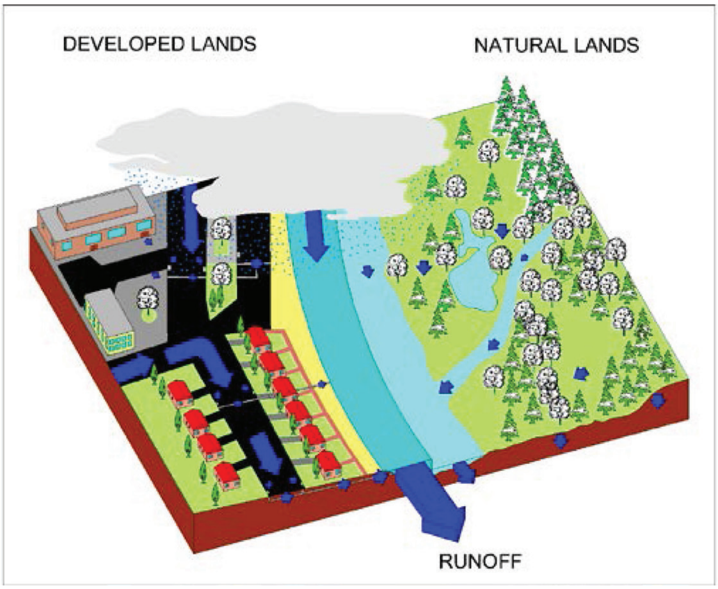


**Figure 3.** The impact of sealed surfaces and urban drainage systems on runoff from developed and natural catchment (modified based on: California WALUP Partners 2008; http://www.coastal.ca.gov/nps/watercyclefacts.pdf)

The main task of sewage systems is, as soon as possible drainage of rainwater to natural pools but in the situation of frequently occurring phenomenon of overloading of sewerage systems, it is worth paying attention to the management of rainwater such as retention and infiltration in place of her appearance (Wałęga *et al*. 2009). A possible solution to restrictions this problem might be also by the introduction of so-called green (KOM 2013, Anderson *et al*. 2008, Urbnews.pl) or green-blue infrastructure (Wagner *et al*. 2015).

## CLIMATE CHANGE AND URBANISATION

### Climate change and urbanisation in USA and Europe

Climate change is heavily related to changes two factors: rainfall and air temperature. According to reports by the Intergovernmental Panel on Climate Change (IPCC 2007) and the European Environment Agency (EEA Report No 12 2012), average air temperature in Europe in years 2002-2011 increased by 1.3°C and it is forecast that in years 2071-2100 there will be an increase in temperature over the European land area by 2.5°C up to 4°C. The largest increase in temperature is predicted to occur in eastern and northern Europe in the winter period and in the southern part in the summer.

It has been noted that the annual rainfall have been increasing, mainly in northern Europe, and decreasing in some parts of the southern Europe (EEA Report No 12 2012) ever since the middle of the 20$^{th}$ century in winter periods. The western part of Europe has noted an increased number of intense rainfall events. It is forecast that an increase in rainfall values will occur in northern Europe (mainly in winter) and a decrease in the southern Europe (mainly in summer). Also, the estimated number of days with intense rainfall will increase.

Urbanisation in Europe results mainly from the development of industrialisation, trade, and services. According to the European Commission (2012), there is a tendency in urban development in European lands in a way that does not carefully examine its future implications. Also, urbanisation is accompanied by a significant number of rural population migrating to cities which, in consequence, results in the increased percentage of urban population in total population of a country or an area. The basic measure of how advanced this process is is the urbanisation index defined as a ratio between urban population and total population. It can be low (up to 40%), medium (40-60%), and high (above 60%) (Jałowiecki 1999). In 2000, Europe (73.4%) was fourth most urbanised region in the world (Table 1) after Northern America (84%), Latin America (75.4%), and Australia and Oceania (74.1%). It is forecast that by 2030 Europe will have placed itself third. It has been observed in the USA over the period 1982-1997 that the pace of urban development of the country (34%) increased two-fold compared to the population growth (15%) in the same time. It is forecast that over the period 2000-2025 the population growth of the USA will reach 22% leading to an almost three-fold increase in urban development of the country (EPA 2007).

**Table 1.** Changes in urbanisation index values in the world in years 1950-2000 and a forecast for 2030 (Balon and Wójtowicz 2005)

| Years / Region | Urbanisation index [%] | | | | | | Forecast [%] |
|---|---|---|---|---|---|---|---|
| | **1950** | **1960** | **1970** | **1980** | **1990** | **2000** | **2030** |
| World | 29.8 | 33.7 | 36.8 | 39.6 | 43.5 | 47.2 | **60.2** |
| Africa | 14.7 | 18.5 | 23.1 | 27.4 | 31.8 | 37.2 | **52.9** |
| Asia (excl. Russia) | 17.4 | 20.8 | 23.4 | 26.9 | 32.3 | 37.5 | **54.1** |
| Latin America | 41.9 | 49.5 | 57.6 | 65.1 | 71.1 | 75.4 | **84.0** |
| North America | 63.9 | 69.9 | 73.8 | 73.9 | 75.4 | 77.4 | **84.5** |
| Australia and Oceania | 61.6 | 66.6 | 71.2 | 71.6 | 70.8 | 74.1 | **77.3** |
| Europe (incl. Russia) | 52.4 | 58.0 | 64.6 | 69.4 | 72.1 | 73.4 | **80.5** |

In the fact of the augmentation in the number of occurrences of heavy rainfall and the expected growth in population in cities, which may result in an increased sealing surface area, there is a risk of rise in instances of local flooding or flooding the area with different areas of the USA and Europe.

## Climate change and urbanisation in Poland

Climate change observed in Poland is relatively small, however its results have recently become more acutely felt because of an increase in the number of extreme weather events.

Average annual temperature values over the period 1971-2000 ranged from 19 to 23°C. According to forecasts (SPA 2013), air temperature will show a clear increase trend in the years 2001-2030 compared to the period of 1971-2000. This means that the entire country will have more days of hot weather, i.e. with temperature above 25°C.This increase will be mostly noticeable in the south-eastern part of Poland.

The average rainfall total value in Poland is 600 millimetres. It is noted that annual rainfall totals in the years 1971-2000 did not change significantly (SPA 2013). The only visible change was noted in the characteristics of rainfall because the number of days with a daily rainfall total of more than or equal to 50 millimetres increased, especially in the south of Poland (Fig. 4).

According to a report of The Ministry of the Environment (SPA 2013) it is forecast that by 2030 climate change will have contributed significantly to unfavourable changes in water relations in Poland. Despite the almost unchanged annual total of rainfall, its character will become more random. This will contribute to longer dry periods and when the rainfall finally occurs it will take the form of heavy rainfalls or storms. Heavy rainfalls (above 20 millimetres a day) are forecast to be more noticeable in the southern part of Poland. This situation is expected to intensify especially in the period 2011-2030. If the heavy rainfalls occur over the areas where the use and development of land resources are managed in an inappropriate way, they will be likely to cause flooding and inundations.

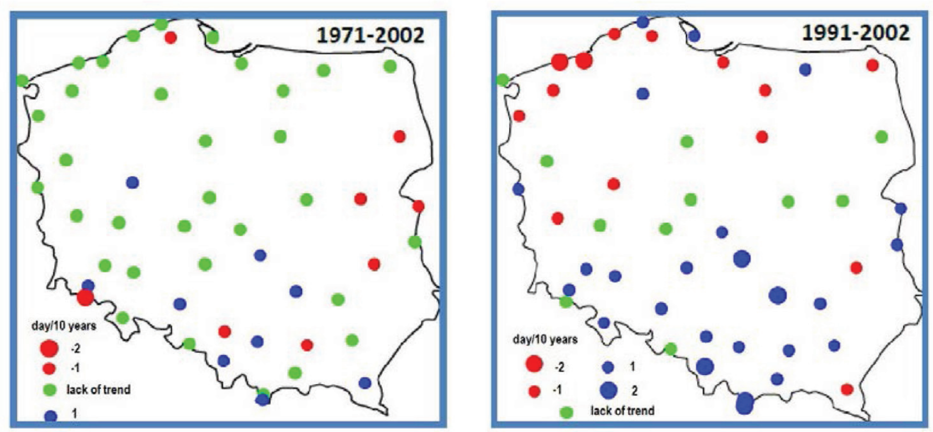


**Figure 4.** Number of days with rainfall ≥ 50 millimetres in Poland: blue dots – increasing trend, red dots – decreasing trend, green dots – no change in trend; the size of dots indicate the intensity degree (modified based on: SPA 2013; http://klimada.mos.gov.pl/wp-content/uploads/2013/10/SPA2020.pdf)

Historical analyses show that the frequency of maximum discharges occurring in rivers was disturbed and increased two-fold in the period 1981-2000 compared to the period 1961-1980 (SPA 2013). Research conducted by Hirabayashi *et al*. (2008) on changing maximum discharges occurrence frequency allows to expect that there will be more events of rivers exceeding their maximum levels in the estuary and the upper part of the Vistula River, as well as an increase in the frequency of maximum levels occurring in the Masurian Lake District (Kowalczak 2011). This means that small changes in annual rainfall and runoff totals may contribute to increased frequency and intensity of flooding (including those urban) in Poland. This is significant considering the volume of flood wave (V). For example, a comparison of two different case scenarios that involve a rainfall event of different exceedance probability *p* (*p*=10% and 50%) and duration of merely 1 hour shows that volume values V increase nearly three-fold in urban catchment as compared to natural catchment (with equal catchment surface) (Bzymek and Jarosińska 2012).

Poland is one of the countries of high urbanisation index, i.e. 60.8% (CSY 2015). What is more, despite the demographic decline, as outlined in the National Spatial Development Concept 2030 (KPZK 2030 2012) by 2030 the people migrating to cities, especially big ones, will have increased.

At the moment, Poland is facing the problem of untidy land use planning system that has its consequences in socio-economic conflicts. One such example is uncontrolled urbanisation resulting in rising costs of building additional infrastructure. In consequence, in areas permanently excluded from use develop dispersed, chaotic, and ill-considered building structures that are not backed up by economic calculation. It seems that such calculations are not undertaken in Poland. Chaotic building developments are also in conflict with legislative provisions that prescribe allocating areas for developments according to current needs. This is why estimated losses constitute 20% per each hectare allocated for development. The cost of building a so-called low-cost house is at least two times higher than building the same house on the land with appropriate urban density and infrastructure (KPZK 2030 2012). It is estimated that social costs of dispersed urban developments in Poland are 30% higher compared to the same costs in Western Europe. In their report Śleszyński *et al*. (2015) confirm that an alarming tendency is continuing fourth year in a row that involves granting legal permits for large areas to be developed into housing buildings, especially single-family ones.

Still a serious problem in appropriate urban planning is the low percentage of built-up areas in cities involved in land use planning (Śleszyński *et al*. 2015). In the end of 2013 four voivodships were covered by urban planning in more than half the size of communes's surface: małopolskie (66.0%, a year before 65.5%), śląskie (64.7 and 63.4%), dolnośląskie (58.8 and 56.9%) and lubelskie (58.1 and 57.6%). In terms of the surface of the entire country, in the end of 2012 urban planning covered it in 28%, and in 2013 the measure only increased by a few points to 28.6%. This shows a clear inhibition in planning works despite the requirements of the Spatial Planning and Development Act (SPA 2020 2013).

Additional problem is posed by the fact that there is no coherent system for monitoring changes in urban land use planning and no relevant research is systematically conducted. What is more, the weakness of local authorities in effective law enforcement in terms of spatial planning makes it possible to violate regulations without consequences.

To sum up, current legal regulations not only fail to provide a solution to the problems of urban land use management but also seem to condone actions of negative impact such as dispersed building developments or extensive land use in cities at the expense of the environment.

## URBAN FLOODING

### Urban flooding in USA and Europe

In years 1950-2006 Europe experienced twelve events of flash flood (due to heavy rainfalls) and river flood (Barredo 2006). The greatest number of floods was recorded in 2002 in six EU Member States: Austria, Czech Republic, France Germany, Hungary and Romania.

The flood events occurred mainly within a geographical belt crossing Europe from the western part of the Mediterranean region (Catalonia and south-western France) to the Black Sea including northern Italy, Slovenia, Austria, Slovakia and Romania (Marchi *et al*. 2010, Barredo 2006). In the Mediterranean and Alps-to-Mediterranean regions flash floods occur mainly in the autumn and are extremely intense. They cover a large stretch of area and the rainfall duration is long. The situation looks different inside the continental land where flash floods often occur during the summer period and are less intense which may suggest the influence of other climate factors. It is difficult to predict the size of the negative effects of flash floods occurrences, however it could be expected that the forecast increase in extreme rainfall events frequency will consequently increase the risk of sudden flood events. It would be of vital importance, in this case, to identify those regions that are most susceptible to local flooding in terms of increased urban land use planning, i.e. land sealing (Marchi *et al*. 2010).

In the USA flash floods occurred mainly in states located in mountain areas of great land slopes as well as in small urban catchments (EEA Report No 2 2012) and their immediate cause were heavy rains. In years 2010-2015 heavy rains and rain storms caused flooding in the following states: Utah (2015), Alabama (2014), Iowa (2011), Arkansas (2010).

### Local flooding in Poland

The events of local flooding are not a new problem in Poland as they have already occurred before. According to Kowalczak (2011) their intensity have increased in the last 20 years. Intense rainfall that occurred over the past dozen or more years resulted in flooding in several cities in Poland. The most notable cases were the flooding in Gdańsk (July 2001), Cracow (May 2010 and July 2014), Warsaw (May 2010 and June 2013), Piaseczno (June 2010), Kańczuga commune – przeworski county (June 2013).

## PREVENTION ACTIONS

It is appropriate in situation of increased flood hazard to implement complex solutions that aim at limiting urbanisation and mitigating flood consequences. Good solutions should take into consideration actions 'in as broad perspective as possible and [be] coordinated at the river basin stage' (Directive 2007), i.e. in the same river valley by reducing runoff, reducing river velocity, limiting the so-called channel straightening (i.e. allowing their natural meanders back), and also in the catchment itself by increasing infiltration (of both surface and underground water), increasing retention capacity of river basin by introducing appropriate retention systems, e.g. underground tanks and bioretention systems e.g. biofilters, ponds, bogs, permeable paving, limiting the quantity and velocity of surface runoff, reducing runoff, implementing green infrastructure, e.g. green rooftops. It is becoming increasingly more important to reconcile the common interests of flood prevention measures and urban land use planning.

### Actions in Europe

Some of the Member States of the EU have introduced strategic programmes based on good practices. These are United Kingdom with *Making Space for Water* (DEFRA 2005) and Holland – *Room for the Rivers* (Programme Directorate 2006). Actions specified in both programmes are focused on increasing retention capacity of river basins. An innovative element is that spatial management planning considers soil protection against urban developments. Also Spain (Andalusia) considered quantitative urbanisation limit for communes up to 40% of the existing urban areas. Denmark introduced an act on urban planning and thus limited building of shopping centres in suburban areas that have not been previously developed. A similar approach is observed in Germany where undeveloped areas may be used only in special cases. Some countries such as Austria, Belgium (Flanders), or Luxembourg introduced solutions that only monitor the number of areas annually used for urban development. Bulgaria, Czech Republic, Slovakia, and Poland introduced a fee that is required depending on the quality of soil (this applies to the soils outside of the administrative city areas) if it needs to be used (CE 2012).

What is becoming increasingly important to note is the use of so-called green infrastructure that, on the one hand, prevents uncontrolled urbanisation and, on the other, increases retention capability. What is more, green infrastructure is one of the priorities of the European Commission as well as regional and national policies (KOM 2013).

An example of such practices can be seen in England where green belts constitute 12% of the total surface. Another example would be green rooftops. As plants absorb rainfall water they largely contribute to reducing runoff to drainage systems. Research show that depending on the measurement location, the values of average rainfall retention on extensive green rooftops are between 30 and 86% (Morgan *et al*. 2012, Stovin *et al*. 2012, CE 2012) in the first few hours of rainfall with daily value of no more than 10 mm. Green rooftop also contributes to significant reduction in temperature in the immediate area. This is important especially in a situation when sealed surfaces in cities become too hot and produce urban heat island effect. Research conducted by Thompson *et al*. (2008) shows that sealed surface temperature (tarmac) is higher by 20°C than unsealed surface (turf). Additionally, by changing the surface from tarmac to turf, urban runoff temperature could be reduced by nearly 10°C.

While cities continue their extensive development, an important element in prevention measures is the regeneration of post-industrial areas. Agencies for land use planning in countries such as England, France, Czech Republic, or Portugal support initiatives promoting reusing post-industrial sites for example for social housing developments (CE 2012). In Stuttgart the Germans took one step forward and by implementing the *Sustainable Land Management Programme* they have introduced a policy of land use management that is consistent with land use planning. In practice, every building plot in urban areas is subject to supervision and entered into a database aided by the GIS system. Each area is catalogued and information is provided about the possibilities of potential building on plots within the area. All information is available on-line (www.stuttgart.de) to view by the City Council or potential investors. What is more, Stuttgart seems to go in line with the rule of *inner development before outer development* in the city according to which over 39% of land is protected as landscape and historic areas, and 25% is covered by woodlands and recreational areas. This makes Stuttgart one of the greenest metropolitan cities in Germany.

Quite a few European cities introduced solutions based on SUDS – *Sustainable Urban Drainage Systems* (CIRIA 2007, CE 2012) that focus on reducing surface runoff and thus increasing infiltration and retention of water, i.e. water storage where rainfall occur. These systems are used as an alternative to traditional storm water drainage systems.

**Actions in The United States of America**

More and more cities in the USA are now facing the problem of urban heat islands. This comes as the effect of extreme air temperatures that are acutely felt by the residents. An example of such city is Chicago which is additionally challenged by strong winds and violent storms.

In order to reduce the negative impact of the heat island effect local authorities of Chicago decided in 2000 to introduce the solution of green rooftop in the building of the seat of government – City Hall. In 2010 over 500 green roofs were during or subsequent implementation, including the roofs of buildings such as schools and museums. They are currently very often used in Chicago and additionally promoted in residential building. To this end, special programmes have been created that aim at facilitating private individuals to build such rooftops (Urbnews.pl).

In one of the industrial sections of Chicago – Pilsen – a new project has been implemented that is based on a holistic approach to natural environment protection including better water management. Emphasis was put on relieving the drainage system during heavy rainfalls. In order to do this, among other things, in the industrial area of Pilsen, sealed surfaces were replaced by permeable ones and rainfall water is discharged by a gutter system. In order to save water in dry periods, streets within the area have been arranged with plants that do not need frequent watering. The abundance of green made Cermak Road recognised as 'the greenest' road in the entire country [Urbnews.pl].

The new system proved to be very economical because the costs of building the green road (as compared to a standard one) are lower by 21% and it is estimated to last one hundred years. Positive effects of the implemented system induced more widespread scale of its use. The idea of the programme from Chicago was also used in Los Angeles (Anderson *et al*. 2008).

Current programmes used in the USA are focused on finding appropriate solutions that will mitigate the effects caused by storm water suitable for the current national development level and with consideration of future developments over the years to come. To this end, the U.S. Environmental Protection Agency (EPA) drafted two strategic documents that include practical rules with regard to the application of technical and non-technical protection measures of the areas that suffer from rainfall water runoff from urbanised areas.

One such strategy is LID (*Low Impact Development*) [www.epa.gov] that has been in application for nearly 10 years now in several places in the USA. The LID constitutes a set of innovative practices on reducing runoff and related pollution by appropriate runoff management in close relation to its origins. In case of redeveloping particular area for building, the LID may be applied as a retrofit practise in order to reduce the volume of runoff or pollution load from this area.

Thus, the aim of the LID is not to inhibit the infrastructure development in the country but maintaining, as much as possible, a site's predevelopment hydrology in catchment (NRC 2009), that is the one from before any urban changes (EPA 2007). This mainly concerns infiltration, evapotranspiration, runoff frequency and volume, runoff reduction, and groundwater recharge. Imitating the natural hydrological cycle by implementing the LID practices protects low-lying areas from damage and the influx of pollution.

The main idea behind the LID is integration of small practical and technical solutions in a given area in place of one large solution (EPA 2007). Instead of, for example, introducing one bigger pond that would seize water from several sub-catchments, the authors suggest that bioretention areas be developed in every yard of surface area by disconnecting vertical gutters from the driveway or removing kerbs, thus creating infiltration areas covered exclusively with grass. It has been concluded that implementing the ID practices gives measurable benefits and lowers costs in relation to conventional storm water practices that are still applied but which have not proved useful. On the other hand, from modelling research by Holman-Dodds *et al*. (2003) transpires that the application of the LID technology is less effective in the event of more intense rainfall.

The other strategic document is BMP, i.e. *Best Management Practices* [www.epa.gov] that contains physical, structural, and managerial set of practices that aim at reducing pollution of drinking water reservoirs by substances that come from dispersed sources including rainfall water runoff from urban areas. Depending on the situation, they may be applied individually or as a combination.

Effective management of objectives decides on the necessity of selecting a particular project or a combination of ecological and engineering practices that will be appropriate in a given situation and which usually involve hydrology, inflow hydraulics, soil characteristics/infiltration rates, water quality, location, and receiving water condition (EPA 2004 vol.1). The countrywide BMP practices may differ from local or regional regulations.

Currently in the USA bioretention gained much importance being, broadly speaking, a technology of temporary rainfall water retention in catchment's recesses. Before, grass swales were used only to seize the rainwater whereas now they are widely used in urban storm water management focused on water quality management of urban runoff. The application of plant biofilters brings measurable benefits by reducing urban runoff impacts, groundwater recharge, quality control, stream channel protection and peak discharge control (for both small storms e.g., 6-month and 1-yr frequency storms, and large storms e.g., 2-, 10 – and 100-yr storms) (EPA 2004 vol.2).

## PREVENTION ACTIONS IN POLAND

### Strategic problems

The most important strategic document in Poland that concerns national land use planning is National Spatial Development Concept 2030 (KPZK 2030 2012). It outlines integrated approach to the issues of spatial planning in relation to the socio-economic development and provides guidance on the directions of joint actions. In the context of water management, emphasis was put on the necessity to increase water retention in urban areas up to 12-15% of average annual runoff from the Polish territory (i.e. 7-9 billion $m^3$) that currently in Europe is merely 6%. It is then proposed that large and small retention and microretention are used that are area-based or adjacent to particular buildings. In order to do this, the location of hydrotechnical objects must be assessed to optimise their usage and the range of impact on balance resources in catchment. Areas designed for retention will be indicated in spatial management plans on the level of voivodships. The other objective is delaying the river runoff to the sea, including a delay runoff of rainwater by, among others, introducing financial incentive for landlords if they decide to limit the amount of rainwater runoff to the drainage system. In view of these assumptions, the main emphasis in spatial planning will be placed on retaining water in the environment and determining the best way of using it while considering, at the same time, maintaining the quality and quantity of water resources.

Other water management planning instruments will also be applied on the national, regional, and local planning level, including those defined in The Water Framework Directive (Directive 2000) and The Floods Directive (Directive 2007), as well as river basin-based water management planning, flood risk management planning, draught effects prevention planning, and the rules and regulations on using area-based and catchment waters. In this regard, Polish legislation has been adapted to the current EU laws (Act 2001).

In the context of planning in river valleys, particular attention was paid to bans or limits for building in river valley areas that are susceptible to floods or inundations, as well as limits for agricultural use of these areas. Building developments will be possible in areas adjacent to arable lands or reservoirs that could be used to retain rainfall waters (during rainfall) or to water the fields (in dry periods). In order to minimise the flood risk in urban areas (agglomerations), there will be an obligation introduced to retain rainwater and use it to sustain the green infrastructure.

The protection of humus-rich topsoil against degradation is regulated by the Protection of Agricultural and Forest Lands Act (Act 1995). In the event of change in land purpose – from agricultural to, for instance, industrial – local authorities may ask to remove the topsoil layer in order to improve the quality of ground in a different area. Failure to obey this regulation should ideally result in fine, however in practice local authorities do not act upon it.

## Local initiatives

According to the definition stated in the Water Law (Act 2001) wastewater is *rainwater or snowmelt included in open or closed drainage systems that come from polluted durable surfaces, especially from cities, ports, airports, and various sites to do with industry, trade, services, or warehousing, also transport depots, roads and parking spaces.* This means that the water that does not enter the drainage system is not considered rainwater waste. What is more, waters that come from the roofs are not qualified as wastewater either.

The more buildings and paved surfaces developed on a plot, the more rainwater stays on the remaining undeveloped surface. In a situation when this water is not managed properly on a particular plot, the possibility to use it may be limited and the runoff may have negative influence on adjacent territories.

The awareness of rainwater retention among landlords is still scarce. Residents do not consider rainfall as wastewater whose treatment is expensive and lies within the responsibilities of the Waterworks and Sewage System Company. The fact that the Company introduces fees for rainwater or snowmelt waste is often met with opposition by local residents (Dziubek 2013) and the disputes must be settled in court (Dziubek 2015). Despite the difficulties, more and more Polish cities decide to introduce rainwater fees. A great simplification could be streamlining those practices that have been used so far and introducing appropriate regulations in terms of fees.

The introduction of fees for rainwater waste often motivates residents to retain rainwater that comes from their plots, its reuse, or personally draining it to the environment, i.e. to their own undeveloped areas, pits/absorbent wells, or retention reservoirs (Technical conditions 2002). Such actions relieve the sewage system to a large extent that then receives only the excess of water during heavy rainfalls. Research of Mrowiec (2015) show that the effectiveness of a system that manages rainwater economically (i.e. uses it for watering gardens, flushing the toilet, laundry) may come to as much as between 33 and 39% of the total daily water demand.

Numerous inundations in Kielce area that were observed mainly in the events of short intense rainfall revealed the poor condition of rainwater drainage system and forced the authorities to introduce additional measures that aim at improving the efficiency of sewage network (Staszewski and Zwierzchowski 2013). These actions have already been continuing a few years and they involve the application of street inlets mountain type of larger size and great shape that impedes clogging, as well as manholes with ventilation openings, and grate manholes in areas especially susceptible to rise of ground water level. The example of Kielce shows that all the elements that serve the purpose of seizing the runoff directly should be measured to fit heavy rainfalls, whereas retention elements to fit the rainfall that gives large totals of water supply.

The Road Administration in Kielce that is also the administrative body of sewage systems forced on building investors the necessity of discussing their projects in terms of water runoff. An investor has a duty to indicate in the plans the place where the rainwater will be drained from the plot area. After the development is finished, the ready works undergo an inspection according to the approved project and issued technical conditions. The exemplary situation from the city of Kielce suggests some of the possible solutions aiming at improving the functionality of rainwater drainage system as well as actions that limit the rainwater runoff to receivers.

The concept of blue-green infrastructure that is based on the principle of responsible investment was proposed in the city of Łódź under the name of Blue-Green Network (Wagner *et al*. 2015). It aims at improving the attractiveness of the recreational area by applying solutions related to ecosystem biotechnologies that treat and retain rainwater falling into the Bzura River. In the city of Radom it has been proposed that a demonstration green-blue infrastructure be developed in order to adapt urban space to climate change. The objective of the project concerns two important issues: 1) reducing the risks that come from outside of Radom and enhance hydrological instability of rivers in the city area, 2) reducing flood hazards and decreasing the urban heat island effect which are the result of the urbanization process of the city.

From 2009 research works have been carried out in the city of Wrocław that concern the use of green rooftops for rainwater retention in Poland and, consequently, delaying the runoff to the receiver. Many years of model research conducted in natural meteorological conditions in Wrocław proved high retention efficiency of green rooftops that was on average 30% for a traditional rooftop and around 80% for the green rooftops (excluding winter periods). The green rooftops demonstrated best retention properties for a daily rainfall total of less than10 millimeters. In consequence, it has been proven that it is possible to delay runoff from green rooftops by several hours from the beginning of rainfall (Burszta-Adamiak 2015).

## CONCLUSIONS AND PERSPECTIVES

In the face of the large extent of human influence on the natural environment and climate change, the problem of flooding in local urban areas both in the world and in Poland is still current. Similarly to the situation in the world, Poland has got many action proposals that are in favour of protecting the developed areas; however these are often only single initiatives of local authorities implemented mainly in those areas that suffer from floodings more frequently. Such approach, despite its positive outcomes and proven hydrological benefits, fail to make use of all the possibilities in form of a coherent system that could efficiently support (or relieve) urban drainage systems. In the vast majority of Polish cities there is lack of a complex programme for rainwater management, especially in those areas that the problems in this respect are most serious.

In order to ensure good conditions of socio-economic development, it is indispensable for the responsible authorities to continue to search for innovative solutions, both organisational and technical, to adapt the situation to climate change and prevent the effects of human activity. In order to implement all the tasks it is necessary to introduce a clear legal system as well as an efficient institutional system that will ensure well-functioning cooperation of the decision-makers, i.e. the State authorities, local and regional authorities, urban planners, architects, scientists, hydrologists, or local communities who will take responsibility for carrying out the tasks of spatial planning policy in the country that currently fails to deliver satisfactory results.

Joining the interests of the decision-making bodies of all different environments could greatly improve the complex approach to urban flooding prevention measures.

## REFERENCES

Anderson C., Nisenson L., Stoner P. (2008). Water Resources and Land Use Planning. Watershed-based Strategies for Ventura County, Local Government Commission, Sacramento.

Bajkiewicz-Grabowska E. (2013). Mała retencja (*Small retention*), http://www.cenniejszaodzlota .pl/artykuly, (in Polish).

Balon J., Wójtowicz M. (2005). Geografia (*Geography*), Wydawnictwo ParkEdukacja, (in Polish).

Barredo J. I. (2006), Major flood disasters in Europe: 1950–2005, Natural Hazards, 42(1) 125–148.

Burszta-Adamiak E. (2015). Dachy Zielone dla zwiększenia retencji wodnej w miastach (*Green rooftops for increasing retention in cities*), www.retencja.pl, (in Polish).

Bzymek B., Jarosińska E. (2012). Wpływ uszczelnienia powierzchni zlewni na odpływ wód deszczowych (*The effect of surface seal catchment on the size of strom water runoff*), Czasopismo Techniczne, Wydawnictwo PK, 1-Ś/2012, ZESZYT 4, ROK 109, http://suw.biblos.pk.edu.pl/resources/i1/i2/i3/i3/i9/r12339/BzymekB_WplywUszczelnienia.pdf (in Polish).

California WALUP Partners (2008). How Urbanization Affects the Water Cycle, Attachment 4, The University of Connecticut, http://www.coastal.ca.gov/nps/watercyclefacts.pdf [accessed: 25.07.2014].

CE (2012). Wytyczne dotyczące najlepszych praktyk w zakresie ograniczania, łagodzenia i kompensowania procesu zasklepiania gleby (*Guidelines on the best practices in terms of reducing, mitigating, and compensating for the process of soil sealing*), Urząd Publikacji UE, Belgia, http://ec.europa.eu/environment/soil/pdf/guidelines/pub/soil_pl.pdf [accessed: 25.07.2014], (in Polish).

CIRIA (2007). The SuDS manual, CIRIA C697, London.

CNT Center for Neighborhood Technology (2013). The Prevalence and Cost of Urban Flooding, Chicago Flood Frequency Estimation Using Continuous Rainfall-Runoff Modelling, *Phys. Chem. Earth* **20**, 5-6, 479-483, http://www.cnt.org/sites/default/files/publications/CNT_PrevalenceAndCostOfUrbanFlooding20141.pdf [accessed: 25.07.2014].

CSY 2015 (*Concise Statistical Yearbook of Poland 2015*), Główny Urząd Statystyczny, p.95, ISSN 1640-3630, Warszawa, http://stat.gov.pl/obszary-tematyczne /roczniki-statystyczne/roczniki-statystyczne/maly-rocznik-statystyczny-polski-2015,1,16.html [accessed: 19.09.2015] (in Polish and English).

DEFRA Department for Environment, Food and Rural Affairs (2005). Making space for water. Taking forward a new Government strategy for flood and coastal erosion risk management in England, http://www.defra.gov.uk/environ/fcd/policy/strategy.htm.

Dziubek J. (2013). Opłaty za ścieki opadowe i roztopowe jako nowy element taryf za zbiorowe odprowadzanie ścieków na przykładzie miasta Głogowa (*Fees for rainwater and snowmelt waste as a new element of fares for waste drainage on the example of the city of Głogów*) [In:] Interdyscyplinarne Zagadnienia w Inżynierii i Ochronie Środowiska 3 (*Interdisciplinary Issues in Environmental Engineering and Protection*), Wrocław 2013.

Dziubek J. (2015). Rozdzielenie opłat za ścieki opadowo-roztopowe i bytowo-gospodarcze na przykładzie miasta Głogowa (*The cost breakdown for rain-snowmelt and communal-industrial waste – the city of Glogow case study)* [In:] Interdyscyplinarne zagadnienia w inżynierii i ochronie *środowiska* (*Interdisciplinary Issues in Environmental Engineering and Protection*) Tom 4, Monografia pod red. Teodory M. Traczewskiej i B. Kaźmierczaka,

Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław 2014.

Dyrektywa Parlamentu Europejskiego i Rady 2000/60/WE z 23 października 2000 r. ustanawiająca ramy wspólnotowego działania w dziedzinie polityki wodnej (*Directive 2000/60/WE of the European Parliament and of Council of 23rd October 2000 establishing a framework for Community action in the field of water policy*) (Dz. Urz. WE L 327 z 22.12.2000, str. 1, z późn.zm.).

Dyrektywa Parlamentu Europejskiego i Rady 2007/60/WE z 23 października 2007 r. w sprawie oceny ryzyka powodzi i zarządzania nim tzw.Dyrektywa Powodziowa) (*Directive 2007/60/WE of the European Parliament and of Council of 23rd October 2007 on the assessment and management of flood risks. Also called the Flood Directive*) (Dz. Urz. UE L 288 z 06.11.2007, str. 27).

EEA Report No 2 (2012). Urban adaptation to climate change in Europe. Challenges and oportunities for cities together with supportive national and European policies, ISSN 1725-9177.

EEA Report No 10 (2006). Urban sprawl in Europe – The ignored challenge, ISSN 1725-9177.

EEA Report No 12 (2012). Climate change, impacts and vulnerability in Europe 2012. An indicator-based report, ISSN 1725-9177.

EPA (2003). Protecting Water Quality from urban runoff, EPA 841-F-03-003, http://www3.epa.gov/npdes/pubs/nps_urban-facts_final.pdf.

EPA (2004). Stormwater Best Management Practice Design Guide: General Considerations, vol. 1, EPA/600/R-04/121. http://nepis.epa.gov/Exe/ZyPDF.cgi/901X0A00.PDF?Dockey=901X0A00.PDF.

EPA (2004), Stormwater Best Management Practice Design Guide: Vegetative Biofilters, vol. 2, EPA/600/R-04/121A. http://nepis.epa.gov/Exe/ZyPDF.cgi/901X0B00.PDF?Dockey=901X0B00.PDF.

EPA (2007). Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices, EPA 841-F-07-006, http://water.epa.gov/polwaste/green/costs07_index.cfm.

Geiger W. (1987). Flushing Effects in Combined Sewer Systems, Proc. 4th Int. Conf. Urban Drainage, Lausanne, Switzerland: 40-46.

Gupta K., Saul A. J. (1996). Specific Relationships for the First Flush Load in Combined Sewer Flows. Water Research30 (5): 1244-1252. doi:10.1016/0043-1354(95)00282-0. ISSN 0043-1354.

Hirabayashi Y., Kanae S., Emori S., Oki T., Kimoto M., (2008).Global projections of changing risks of floods and droughts in a changing climate, Hydrological Sciences Journal, 53:4, 754-772, DOI: 10.1623/hysj.53.4.754.

Holman-Dodds J.K., Bradley A.A., Potter K.W. (2003). Evaluation of hydrologic benefits of infiltration based urban storm water management. Journal of the American Water Resources Association, 39(1): 205-215.

IPCC (2007). Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)].IPCC, Geneva, Switzerland, 104 pp.

Jałowiecki B. (1999). Płaszczyzny urbanizacji (*Urbanisation tiers)*, [In]: Sławomir Solecki, Marian Malikowski: Społeczeństwo i przestrzeń zurbanizowana (*Society and the urban area*), Rzeszów: WSP, s. 193-196. ISBN 83-7262-024-5, (in Polish).

KOM (2013). Komunikat Komisji do Parlamentu Europejskiego, Rady, Europejskiego Komitetu Ekonomiczno-Społecznego i Komitetu Regionów, Zielona Infrastruktura – zwiększanie kapitału naturalnego Europy (The Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, *Green Infrastructure − increasing of natural capital of Europe*), Bruksela, 6.5.2013, KOM(2013)249.

Kowalczak P. (2011). Zmienność klimatu a przyczyny powodzi w Polsce (*Climate variability and the causes of the floods in Poland*), Polska Akademia Nauk PAN, Poznań, http://www.umweltaktion.de/pics/medien/1_1324305988/Vortrag_Kowalczak.pdf, (in Polish).

KPZK 2030 (2012). Koncepcja Przestrzennego Zagospodarowania Kraju 2030 (*National Spatial Development Concept 2030*), Monitor Polski Nr 252, Załącznik do uchwały nr 239 Rady Ministrów z dnia 13 grudnia 2011 r. (poz. 252).

Marchi L., Borga M., Preciso E. and Gaume E. (2010). Characterisation of selected extreme flash floods in Europe and implications for flood risk management, Journal of Hydrology, 394(1–2), 118–133.

Morgan S, Celik S., Retzlaff W. (2012). Green roof stormwater runoff quantity and quality, Journal of Environmental Engineering, 139: 471–478.

Mrowiec M. (2015). Mikroretencja na terenach zurbanizowanych (*Microretention in urbanised areas*), Wodociągi i Kanalizacja nr 9, http://e-czytelnia.abrys.pl/wodociagi-kanalizacja/2015-9-868/temat-numeru-10216/mikroretencja-na-terenach-zurbanizowanych-20535, (in Polish).

NOAA National Oceanic Atmospheric Administration, Flash flood, http://www.srh.noaa.gov/mrx/hydro/ flooddef.php [accessed: 16.07.2014].

NRC National Research Council (2009). *Urban Stormwater Management in the United States,* Washington, DC: The National Academies Press.

Programme Directorate (2006). Approved decision Room for the river, http://www.ruimte voorderivier. nl/english/room-for-the-river-programme [accessed: 15.07.2014].

RCB Rządowe Centrum Bezpieczeństwa (2013). Powódź w obliczu zagrożenia (*Flood in the face of hazard*) Warszawa, http://rcb.gov. pl/?page_id=14, (in Polish).

Rozporządzenie Ministra Infrastruktury z dnia 12 kwietnia 2002 r. w sprawie warunków technicznych,jakim powinny odpowiadać budynki i ich usytuowanie (*Ministry of Infrastructure Regulation from 12th April 2002 regarding the technical conditions, which should be fulfilled in case of the buildings and their placement*), (Dz.U z 2002 r. Nr 75 poz. 690).

Sachsen.de (Verwaltungsstruktur des Sächsischen Staatsministeriums für Umwelt und Landwirtschaft), http://www.umwelt.sachsen.de/umwelt/boden/12204.htm [accessed: 14.07.2014].

Staszewski G., Zwierzchowski W. (2013). Doświadczenia w zagospodarowaniu wody deszczowej na przykładzie miasta Kielc(*Case studies of rainwater management in Kielce*), MZD Kielce, http://www.sejmik.kielce.pl/temp/zdjecia_kat/35763/doswiadczenia_w_zagosp_wod_ opadowych.pdf [accessed: 19.09.2015].

SPA 2020 (2013). Strategiczny plan adaptacji dla sektorów i obszarów wrażliwych na zmiany klimatu do roku 2020 z perspektywą do roku 2030 (*National Adaptation Strategy (SAP)*), Ministerstwo Środowiska, http://klimada.mos.gov.pl/wp-content/uploads/2013/10/SPA2020.pdf [accessed: 15.07. 2014].

Stovin V., Vesuviano G., Kasmin H. (2012). The hydrological performance of a green roof test bed under UK climatic conditions, Journal of Hydrology 414/415: 148 –161.

Śleszyński P., Komornicki T., Deręgowska A., Zielińska B. (2015). Analiza stanu i uwarunkowań prac planistycznych w gminach w 2013 roku(*Analysis of the conditions of planning works in communes in 2013*), Instytut Geografii i Przestrzennego Zagospodarowania PAN na zlecenie Ministerstwa Infrastruktury i Rozwoju, Warszawa, p. 121.

Thompson A.M, Kyunghyun K., Vandermuss A.J. (2008). Thermal characteristics of stormwater runoff from asphalt and sod surfaces, Journal of the American Water Resources Association 44(5):1325-1336.

Urbnews.pl Cermak Road w Chicago, http://urbnews.pl/cermak-road-chicago-najzielensza-ulica-stanow-zjednoczonych/ [accessed: 25.07.2014].

Urbnews.pl Zielone dachy w Chicago (*Green Roofs in Chicago*), http://urbnews.pl/zielone-dachy-chicago/ [accessed: 25.07.2014].

Ustawa o ochronie gruntów rolnych i leśnych z dnia 3 lutego 1995 r. (*Act of Protection of Agricultural and Forest Lands*) Art. 14, ust. 1 i 2.

Ustawa o planowaniu i zagospodarowaniu przestrzennym z dnia 27.03.2003 r. (*Act of Spatial Planning and Development*), (Dz.U. nr 80, poz. 717).

Ustawa Prawo wodne z dnia 18 lipca 2001 (*Water Law from 18th July 2001*), Załącznik do obwieszczenia Marszałka Sejmu Rzeczypospolitej Polskiej z dnia 10 stycznia 2012 r. w sprawie ogłoszenia jednolitego tekstu ustawy – Prawo wodne, tekst jednolity: Dz.U. 2012 poz. 145 z późn. zm., http://isap.sejm.gov.pl/DetailsServlet?id=WDU20120000145 [accessed: 19.09.2015].

Wagner I., Krauze K., Jurczak T., Zalewski M. (2015). Zielono-błękitna infrastruktura a retencja krajobrazowa w miastach (*Green-blue infrastructure and landscape retention in cities*) Wodociągi i Kanalizacja nr 9, http://e-czytelnia.abrys.pl/wodociagi-kanalizacja/2015-9-868/temat-numeru-10216/zielono-blekitna-infrastruktura-a-retencja-krajobrazowa-w-miastach-20534.

Wałęga A., Chmielowski K., Miernik W. (2009). Seminaturalne systemy odprowadzania i oczyszczania wód opadowych z terenów zurbanizowanych – aspekty prawne i techniczne (*Semi-natural systems of drainage and treatment of storm sewage from the urbanized areas – legal and technical aspects),* Infrastruktura i Ekologia Terenów Wiejskich, nr 6.

Dr inż. Elżbieta Jarosińska
Cracow University of Technology
Institute of Water Engineering and Water Management
ul. Warszawska 24, 31-155 Kraków
ejarosin3@gmail.com

Recceived: 10.03.2016
Accepted: 02.06.2016