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Urban Flooding and Sustainable Land Management – Polish Perspective

Powodzie miejskie i zrównoważona gospodarka terenami – polska perspektywa

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Abstract
There have been many events connected with damaging abundance of water in Polish towns in recent decades. Some of them have been caused by flood waves on rivers passing through towns. Others have been caused by intense precipitation overwhelming the capacity of storm sewer systems. A brief review of the topical area of urban floods in Poland in last decades is provided. Mechanisms responsible for increase of flood risk are discussed in a systematic manner. In result of multiple mechanisms, the frequency of inundations has increased and is likely to increase further. Examples of sustainable management issues related to floods are reviewed. Flood protection and flood preparedness are examined in the sustainability context.

Key words: urban floods; land management; sustainable development; Poland

Streszczenie
W ostatnich latach w Polsce miało miejsce wiele niebezpiecznych zdarzeń związanych z niszczącą siłą wody. Niektóre z nich były spowodowane falami powodziowymi płynącymi przez mijające miasta rzeki. Inne uwarunkowane były intensywnymi opadami przekraczającymi pojemność systemów kanalizacji deszczowej. W tej pracy dokonano przeglądu tego typu zdarzeń z okresu ostatnich kilku dekad. Omówiono i usystematyzowano mechanizmy przyczyniające się do obserwowanego wzrostu zagrożenia powodziowego. Przedstawiono przykłady zrównoważonego zarzadzania w kontekście powodziowym. Przeanalizowano także istniejącą ochronę przeciwpowodziową i poziom przygotowania na przyjęcie powodzi.

Słowa kluczowe: powodzie miejskie, zarządzanie terenem, zrównoważony rozwój, Polska

Introduction

Since the dawn of civilisation, destructive floods have jeopardised settlements located near rivers. Despite developments in technology and extensive investments in flood control works, flood damages are indeed growing, reaching globally tens of billions of USD, per annum, in both developed and developing countries. The number of floods in Europe exceeding selected severity and magnitude thresholds has been increasing (Kundzewicz et al., 2013). Damages are particularly high in urban areas. This can be seen in context of the increasing proportion of population living in towns – more than 50% globally. Cities constitute a driving force of the economy. Indeed, the 21st century can be called the age of cities (Sztumski, 2013).
In recent decades, several Polish towns have been hit by inundations. Major floods, with high material damage and fatalities, have been caused by passage of a flood wave on rivers running through towns.

Many problems have resulted from intense precipitation on largely impervious urban areas with insufficient storm sewerage network.

The most destructive flood ever recorded in Poland was the July 1997 flood on the rivers Odra, Vistula, and their tributaries (Kundzewicz et al., 1999) resulting in high material damage and fatalities in urban areas. Having inundated the town of Racibórz (65 000 inhabitants), the River Odra devastated further large towns located downstream: Opole (131 000) and Wrocław (700 000). The flood protection system of Wrocław, designed for a flow rate of 2400 m^3 s^{-1}, had to fail since the peak flow rate was about 50% higher. The absolute all-time records of water level were observed in all gauges of the upper and medium reaches of the River Odra and, in result, all towns on the Odra in Poland, upstream of Słubice, were damaged by the 1997 flood. Słubice itself, laying in depression, with its centre about 4.5 m below the flood water level in the River Odra, was the most upstream town on the Polish Odra that avoided inundation in July 1997. The levees survived but since the risk of failure was high, the population of the town was evacuated. The nationwide toll for both Odra and Vistula floods of summer 1997 was an all-time high in Poland as far as economic losses are concerned. The estimates of material losses range from 2 to 4 billion US$ (at 1997 value), indicating that the costs were of much significance to the national economy. The number of fatalities reached 54. The number of flooded towns and villages was 2592 (1362 totally and 1230 partially inundated). The flood caused damage to 46 000 houses and apartments and the number of evacuees was 162 000. Around 6650 km^2 of land were flooded, of which over 4500 km^2 consisted of agricultural fields. The flood destroyed about 480 bridges and damaged 245. The serious damage to roads and railways occurred at 3000 km and 2000 km, respectively. Loss of 1900 cattle, 5900 pigs, 360 sheep and around 1 million poultry was recorded. Embankments were damaged or seriously weakened at a distance of about 1100 km.

The 1997 flood was extensively covered by Polish media. For several weeks, it was the dominating topic in the press and the principal theme of cover stories of weekly magazines.

Another, more recent, train of destructive floods occurred in Poland in 2010 (Kundzewicz et al., 2012a), causing high material damage and fatalities, also in urban areas.

In recent decades, there have been many problems related to intense precipitation in urban areas, throughout the country, e.g. in Warsaw, Poznań and the Wielkopolska Province (e.g. Swarzędz, Kostrzyn – cf. Fig. 1, Luboń, Mosina). Spectacular problem arose in the Three-Towns (Gdańsk, Gdynia, Sopot) when on 9 July 2001 intense rain fell. In Gdańsk, precipitation of 90 mm was recorded within 2 hours and roads down the slope turned into torrential streams. In result of this urban flooding, 134 buildings were badly damaged and had to be torn down.

Figure 1. After intense rain water inundated the underground pedestrian passage under railway in Kostrzyn Wielkopolski in June 2010 (Kowalczak et al., 2010)

Virtually, in every year there are numerous inundations caused by intense precipitation in Poland. In June 2013, an important road within the capital city of Warsaw was inundated by water from intense rain to the depth of up to 2.5 m and this led to a political crisis as the mayor was declared guilty and heavily criticized by the opposition.

Flood disasters and flood defences can be regarded in the context of sustainable development, even if this notion may mean different things to different people, some definitions lend themselves well to applications in the topical area of floods:

a) assuring that the development meets the needs of the present without compromising the ability of future generations to assuring their own needs (best known, classical, definition, so-called *Brundtland definition*, after WCED, 1987);
b) living on the *interests* from the Earth *capital* without depleting (preferably, with augmenting) the capital itself, as inherited from former generations (cf. Kundzewicz et al., 1987);
c) improving the quality of human life (attaining non-decreasing human welfare over time, with welfare understood more broadly than GDP, including assets related to environment) within the carrying capacity of supporting ecosystems (IUCN, 1991).

Floods bring destruction to cultural, and in particular – urban, landscapes, with their infrastructure – buildings, industry plants, historical monuments, communication infrastructure: bridges, roads, and railways, inherited from former generations. Floods may destroy the human heritage and undermine the development by breaking continuity.

Mechanisms of changes in flood risk in urban areas in Poland

Kundzewicz and Schellnhuber (2004) generally attributed changes in flood risk to three categories of mechanisms: changes in socio-economic, terrestrial, and climate/atmospheric systems. Changes in socio-economic systems of relevance to flood risk embrace land-use change, increasing exposure and damage potential, floodplain development, growing wealth in flood-prone areas, and changes in risk perception. Damage potential grows with economic growth (Fig. 2). Changes in terrestrial systems include land-cover change – urbanization, deforestation, elimination of natural inundation areas (wetlands, floodplains) and river regulation – therein construction of embankments. Finally, the category of changes in climate embraces changes in water holding capacity of the atmosphere in the warming climate, increase in intense precipitation, changes in snow cover, seasonality of precipitation, and weather circulation patterns. All these mechanisms are of relevance to flood generation in urban areas.

In result of mechanisms of change listed above, water level in a river gauge in an urban area with a certain return period, e.g. 1000 years (i.e. with annual exceedance probability of 0.001), used as a design flood in urban areas, where damage potential is very high, and growing, and therefore adequate level of protection is necessary, may have already increased and is projected to increase further. That is, a 1000-year water level determined for past-to-present is likely to be attained more frequently in the future in many areas, i.e. it will correspond to a return period of fewer years (Fig. 2, Kundzewicz et al., 2010). This rhymes with the *Leitmotiv: stationarity is dead* of Milly (et al., 2008).

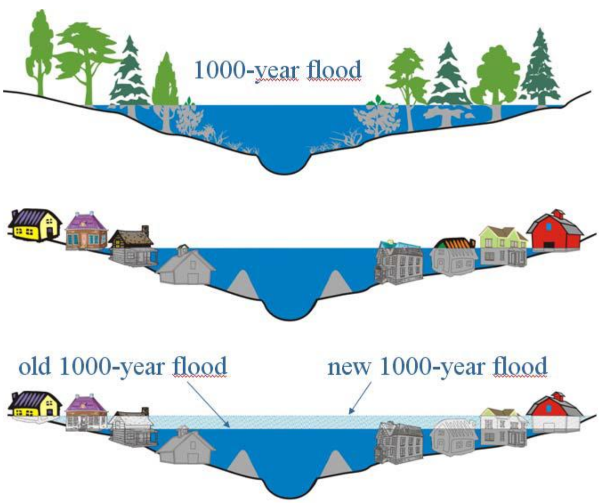

Figure 2. Changes in socio-economic and terrestrial systems induce changes in flood risk (Kundzewicz et al., 2012)

Urban areas have shown particularly strong human impact. Human activities result in change of the water systems, climate (at all scales), and vegetation. There is a growth of impervious (sealed) areas that substantially reduces infiltration into the ground, transformation of soils – reduction of storage, elimination of small surface retention areas, and drainage – dewatering of shallow groundwater and rain waters. Impermeable roofs, roads, pavements and car parking constitute an increasing portion of urban areas. The value of the roughness coefficient gets lower, green areas are shrinking and small rivers are often conducted underground. In result, flood water in urban areas is conveyed faster from the source of runoff generation to the receiving areas, than in rural areas, where higher infiltration rates occur that enable recharging groundwater and where wetlands and meadows provide water storage buffers thus lowering the inflow to rivers. Unfortunately, nowadays, drainage of wetlands and channelization of waterways have reduced storage and infiltration capacity of floodwaters (Kowalczak & Kundzewicz, 2011). Levees are constructed and flood plains are cut off (Fig. 2). In brief, land-use change leading to land-cover change has resulted in reduction of storage, a higher flood peak, and a shorter time-to-peak.

The distribution of the frequency of high flows changes adversely, due to the increasing portion of hydrologically active (i.e. runoff-generating) areas. Water storage in all its guises is reduced, and the amplitudes of high flows increase. Another source of problems is the increasing loading of the storm sewerage network, dewatering the growing urban fabric, without creation of adequate water storage space. Storm sewerage can be rated as increasingly insufficient and expensive.

Increasing flood exposure results from human encroachment into floodplains and economic development of flood-prone areas. Many wrong locational decisions have been taken, and the assets at risk from flooding are high, and growing. Risk perception has changed – people feel more secure behind the dikes, but this feeling is not justified, as there is no such thing as absolute flood safety.

Anthropopressure causes the tendency to use additional land, that is also the flood plains that attract development due to their flatness, soil fertility, proximity of water, and aesthetics.

In mountainous areas, urban and semi-urban development extends to hilly slopes which are at risk of landslide and debris flows. The problem is increasing with residential area development on the hill side, deforestation, and road construction (Kundzewicz & Takeuchi, 1999).

Management issues

In this section a review of management issues will be tackled. Particular flood preparedness measures will be looked at from the sustainability perspective.

There exist a roster of strategies for reducing flood losses by flood protection and management and all of them are of relevance to urban areas. They may modify (Kundzewicz & Schellnhuber, 2004):

- susceptibility to flood damage;
- flood waters; or
- impact of flooding (during and after flood).

Flood protection measures can be structural (*hard*) or non-structural (*soft*). Dams and flood control reservoirs, diversions, etc. belong to the category of structural flood mitigation measures. Constructing reservoirs where the excess water can be stored allows a regulated temporal distribution of streamflow and helps alleviate the flood problem by flattening destructive flood peaks.

A sample of possible non-structural (*soft*) means include:

a) zoning, regulation for flood hazard areas development leaving flood plains with low-value infrastructure, e. g., vegetation occasionally flooded;
b) flood mitigation system of forecasting, warning (issuing and dissemination), evacuation, relief and post-flood recovery;
c) flood insurance, that is division of risks and losses among a higher number of people over a larger space and time; and
d) capacity building (improving flood awareness, understanding and preparedness), enhancing participatory approach.

An important flood protection measure is the source control that is watershed management including land use and soil conservation to minimise surface runoff, erosion and sediment transport. This idea is implemented by enhancing infiltration e.g. via pervious pavements and parking lots, local storages: ponds, building and groundwater storages (Kundzewicz & Takeuchi, 1999). Enhancing retention counteracts the adverse effects of urbanisation (growth of flood peak, drop in time-to-peak of a hydrograph, drop in roughness coefficient and in storage potential) and channelization (faster flood conveyance through shortened and straightened rivers).

The flood damage potential is increasing because of urbanization and over-reliance on the safety provided by levees and reservoirs etc. Typically, dikes offer adequate protection against small and medium size floods, i.e. the number of damaging floods in this range is decreasing. Yet, when the deluge is of disastrous size and the dikes break (Fig. 2), the losses in a dike-protected landscape are higher than would have been in a natural state (without levees, Kundzewicz & Takeuchi, 1999).

An important measure that lends itself well to solving the urban flooding problems is spatial planning (*room for rivers*), based on zoning and restriction of new development. However, we have to provide a high standard of protection for existing built-up areas of high historical and material value. As an alternative (and/or a complement) to structural flood defenses, rainwater management (*catch water where it falls*) could be used, providing multiple benefits, such as increasing the available water resources and enhancing ecosystem services, in a cost-effective way.

Regulations on zoning (identifying direct flood risk areas, with ban on construction; and potential flood risk areas (if a levee breaks), with restricted development, have been in place in Poland, but they have not been effectively enforced yet.

Levees protecting agricultural and rural areas upstream of a large town eliminate natural storage areas, whose presence would be beneficial for catching the water and weakening of the impetus of a flood wave. Hence, the elimination of flood plains upstream of a town may adversely affect the flood protection of the town. During the Odra River flood in Poland, in July 1997, the idea emerged to intentionally break levees upstream of the large town of Wrocław, in rural areas. The inundation of rural areas was envisaged to be a lesser evil, aimed at reducing aggregate flood damage by avoiding inundation of a large town, with much higher flood-damage potential. However, the idea was not implemented, because of strong resistance of the farmers and, as it turned out later, in this particular case, the envisaged sacrifice of the rural areas indeed would not have saved Wrocław. The masses of water propagating along the River Odra were simply too large in comparison to the emergency storage volume that would have been gained by a levee break. However, the lesson from this experience was learnt: the flood time is not the appropriate moment to consider, in the improvisation mode, technicalities and consequences of breaking a dike. This should be studied and tested well in advance, in a non-flood time. This remark actually refers to the entirety of flood protection / flood preparedness system that should be prepared beforehand, in flood-free time. No experiments should be conducted during a flood event.

There was a controversy on reservoir management between the upstream and downstream riparians observed during the large flood in July 1997 (see Kundzewicz *et al*., 1999): large spills from upstream water storage reservoirs were blamed for aggravating the flood damage in several towns downstream.

In Poland, several activities aimed at strengthening the flood protection and preparedness system have been undertaken since the 1997 flood. Large, and costly, programmes like Programme for the Odra 2006 and programme of flood protection in the drainage basin of the Upper Vistula River have been proposed. Yet, it remains to be seen whether these very costly activities will indeed substantially reduce the flood risk.

European Union legislation aims to alleviate problems related to flood risk reduction. Since 1 May 2004, the Republic of Poland has been a Member

State of the European Union (EU); hence, obeying to the advanced EU environmental legislation. Implementation of the Floods Directive of the European Union (CEC, 2007), a unique act of international law, probably the most advanced worldwide, brings hope that flood risk and vulnerability will be reduced at the level of the whole 28-country organism of the EU, including Poland. EU Member Countries are obliged to adhere to Floods Directive and prepare flood hazard maps and flood risk maps for areas which could be flooded by floods with a low probability (or extreme event scenarios); floods with a medium probability (likely return period ≥ 100 years); and floods with a high probability. The EU Floods Directive foresees that Member States shall ensure that the flood hazard maps and flood risk maps are completed by 22 December 2013. Member States shall also ensure that flood risk management plans are completed and published by 22 December 2015. According to the Flood Directive, flood risk management plans should be periodically reviewed and – if necessary – updated.

The advent of flood-risk maps and potential flood-damage maps, and plans for flood risk management is healthy, and augurs well for urban flood risk reduction in Poland. However, the so-far flood risk awareness in the country is not adequate. For many dwellers of riparian areas, the finding that they have been living in a 100-year flood area is a shocking news. Beautiful locations near a river used to be among the most expensive sites in some towns. When the flood risk maps become public, the impact on the real-estate market can be very serious and the value of some properties (land and buildings) are likely to drop dramatically. Insurance companies would propose high (in some cases, unaffordable) premiums, because of the high flood risk in such locations. Nevertheless, the EU Floods Directive is a fair rule, enhancing implementation of the *risk-taker pays* principle, likely to enforce the appropriate, and much needed, zoning.

Klijn (et al., 2004) made a call in the Netherlands to move away from resistance to resilience approach in the flood management policy. The notion of resilience, understood as the ability of a system to withstand a disturbance, incorporates hazard control (e.g. heightening of dikes). However, higher dikes can give false feeling of perfect protection against floods enhancing more development in floodplains behind dikes. Then, less room is available for flood waters between dikes, because floodplains are cut off. This, again, necessitates additional heightening of dikes. Resilience is understood as system's ability to recover easily and quickly from a disturbance. In this approach, land use must be adapted to allow the river to temporarily inundate large areas during floods while reducing flood damage.

This attitude is similar to replacing the policy of *fail-safe* systems by *safe-fail* systems (Kundzewicz & Takeuchi, 1999). It is impossible to design a system that never fails (fail-safe), in general, and in flood protection in particular. What is needed is to design a system that fails in a safe way (safe-fail). Since a flood protection system guaranteeing absolute safety is an illusion, a change of paradigm is needed: it is necessary to live with the awareness of the possibility of floods. No matter how high a design flood for a structural defence is, there is always a possibility of having a greater flood, inducing losses. Rather than trying, in vain, to eradicate floods, one could accommodate them in planning and learn to live with them, preparing for flooding and reducing damages. It is advisable to restore natural processes in the urban environment in order to enhance infiltration and slow down the devastating effects of high runoff values. Such advantageous processes can be mimicked using swales, eco-roofs, constructed wetlands and detention basins.

Providing effective flood protection to the dwellers of the Kozanów estate in Wrocław, which was inundated in both large recent flood events in 1997 and 2010, would be prohibitively expensive. Hence, a conflict has emerged between the groups of inhabitants of Wrocław – those living in the estate and those not living there. The former wish to be protected, no matter what the cost (to be borne by taxpayers), while the latter subscribe to the *risk-taker pays* principle, and do not want non-resident tax-payers to support the costly protection of people living in unsafe, flood-prone, areas (Kowalczak & Kundzewicz, 2011).

A common reason for controversies is the lack of synchronization of setting the law and planning new endeavors. Rainwater management in Polish towns is basically an area dominated by fiscal politics, whereby a tax is introduced, determined according to some measures of impervious area.

Management of rain waters in urban areas has been embraced in programmes of small storage and biologically-active surfaces in local plans of spatial arrangements in many European countries (e.g. Austria, Denmark, France, Germany, Great Britain, the Netherlands, Sweden, Switzerland). Rainwater management has been also introduced in several Polish towns (e.g., Leszno, Krotoszyn, Gdańsk). However, in Poland, several problems related to rainwater management (of social, environmental, economic, legal, planistic and aesthetic nature) and a number of barriers (planning-organization, legal, economic, social) can be distinguished. The traditional attitude is as follows: rainwater has to be fed to storm sewage. There is lack of awareness and lack of examples of good practices. It is necessary to develop a system of information on risk for the population, and to undertake awareness raising action (Januchta-Szostak, 2011)

Poznań is one of the towns in Poland, where the increase in storm sewer drainage in recent decades has been very strong: from 1.3×10^6 m^3 in 1945 to 20.3×10^6 m^3 in 2000. As a result, surface runoff and infiltration decreased considerably. Yet, intense precipitation on increasingly sealed areas is a tough challenge to the storm sewer drainage, designed for less demanding conditions. Hence, measures to reduce impermeable areas have been considered, but their effectiveness is questionable. The municipality of Poznań introduced a precipitation-drainage tax, determined according to the roof area of a property. The debate about the principle of taxation has taken place in different towns, and a range of solutions were envisaged. The tax included impervious areas; e.g. in Elbląg, it was calculated according to the area of pedestrian pathways, roads and car parks (Kowalczak & Kundzewicz, 2011).

During a river flood, levees serve as flood protection, whereas during an urban inundation caused by intense rain on the town side of the levee, structural defense is a drawback hindering conveyance of water out of the inundated town to the river network.

Different flood types require different measures. For example, in Słubice, in case of an ice jam flood there is a 4 h advance notice for evacuation. If the flood wave on the Odra is caused by snowmelt in the mountains, the advance notice is of 6-7 days, so that there is ample time to undertake effective flood action.

Difficult and potentially conflict-generating problems are related to flood insurance. During the 1997 flood, the then Prime Minister of Poland, Włodzimierz Cimoszewicz, stated soberly that only insured inhabitants can count on receiving compensation for flood damage. This undiplomatic statement (essentially right but delivered when many Polish people suffered acute flood losses) was heavily criticized and is believed to have contributed (among other things) to the fall of the government. However, flood insurance is expected to play an increasing role in Poland and to enhance sustainable land management.

The 1997 flood has taught humility to arrogant politicians and militant environmentalists alike. The new reservoir in Czorsztyn, subject to violent and long-lasting dispute that had lasted for decades, proved to be very much needed during the flood, saving settlements from inundation.

Sustainable development context

The ecologic, economic, and socio-cultural goals of sustainable development should be realised to provide a decent life for people, while preserving the existing environmental capabilities (Rogall, 2009).

Sustainable development should have a built-in mechanism of maintenance of resilience against surprises and shock, such as a violent abundance of destructive water. A common interpretation of sustainable development is that civilisation, wealth (human and natural capital) and environment (built and natural) should be relayed to future generations in a non-depleted shape. This can be illustrated by the notion that we borrow the environment from future generations. Devastating floods destroy cultural landscapes and undermine sustainable development by breaking continuity and impairing the quality of life (Kundzewicz, 1999). While flood protection is necessary to the present generation to attain a fair degree of safety from disastrous events, it must be done in such a way that future generations are not adversely affected. According to the UK Environment Agency (1998, p. 9), sustainable flood defense schemes should *avoid as far as possible committing future generations to inappropriate options for defence.* When building flood protection systems. one should not paint oneself into a corner from which retreat is impossible (or unaffordable).

Many objects of flood protection infrastructure have been criticised in the context of sustainable development as solutions closing options for future generations and introducing inacceptable disturbances in ecosystems (Takeuchi et al., 1998). *Soft* measures that do not involve large structural components can be rated as more sustainable than hard measures, yet the latter may be indispensable in particular circumstances (e.g. when very valuable urban fabric has to be protected also against large floods). Distributed, small-scale, structural approaches, such as source control, flood proofing, building codes, extending permeable areas etc., are also sustainable.

Gardiner (1995) compared options of flood defence and assessed their performance from the viewpoint of sustainable development. The rating ranged from very good for source control to bad / very bad for channelized rivers. He also noted that, among the many advantages of source control, it conserves resources, buffers systems from possible climate change impacts, conserves energy through increasing retention *at source*, promotes biodiversity by retaining water, improves self-sufficiency and recharges groundwater.

In order to measure the progress towards sustainable development, suitable criteria and indicators are needed, assisting one to steer action, to make decisions and to increase focus on sustainable development. One can take recourse to a general proposal of four conceptual criteria for evaluation of sustainability, that is: fairness, reversibility, risk, and consensus, recommended by Simonovic (see Takeuchi et al., 1998), all relevant in the context of flood defences.

Fairness or equity means that flood protection should be extended to all members of the society. Yet, difference in vulnerability to floods even between neighbouring households can be enormous and there is a social dissonance between the urban poor and the wealthy citizens (Sztumski, 2013). The notion of fairness may come about when examining management issues related to recovery after flood. Restoration after natural disasters, such as floods, can be lucrative to some companies that maximize profits (Klein, 2007).

Reversibility is not a strong feature of large, structural flood defences. Yet, there have been several examples of decommissioning of dams (e.g. in France) and of intentional removal of dikes, i.e. renaturalization of rivers (e.g. in Germany and Switzerland). In some cases, the cost of transformation of an engineered system to the original unengineered state happened not to be prohibitive (Takeuchi et al., 1998).
Risk is typically understood here as a product of hazard (probability of failure), being usually low, and consequences, usually high. The concept of risk can be illustrated in the context of structural flood defences – dikes. Existence of dikes creates a false feeling of absolute safety and may trigger intensive development of low-lying areas. If a dike breaks, this defence does not act as a protection, but rather as an amplifier of destruction; flood losses without a dike would have been lower.
Consensus means that involved and affected parties should agree as to the programme of flood protection and management. Yet, striving for absolute consensus can suffocate decision-making as clearly visible in some newly democratised countries.
One could add to these criteria also a measure of efficiency and synergism; a multi-purpose reservoir may have a number of functions related to sustainability: flood protection, water supply, hydropower, navigation, etc.
Gardiner (1995) suggested using four groups of criteria to compare options of flood defence and assessed their performance from the viewpoint of sustainable development. These criteria related to global environment (resilience to climate change, energy efficiency, biodiversity), inter-generational equity (retention of strategic adaptability / future options), natural resources (quantity and quality of surface water and groundwater, wildlife habitat) and local environment quality (morphological stability, landscape and open land, recreation and amenity and enhancement of river environment).
Criteria, indicators and checklists could be used to compare options for flood protection. Usually, there exist a spectrum of means to achieve a development target of concern, with differing values of quality criteria. One has to evaluate the advantages and disadvantages of alternative means for flood protection, both structural and non-structural, weighting their pros and contras (not only short-term benefits but also long-terms impacts and side effects, Kundzewicz, 1998). The viable alternatives should be revealed, made transparent to the public, subject to public discussion and, finally, the decision as to how to solve the problem should be accepted by the society.
Examples of quality indices which could be used when comparing alternative flood preparedness systems may relate to socio-economic and financial feasibility, related investment and operational costs; degree of intervention in the natural regime, stress to ecosystems and humans, use of energy and raw materials, and safety, risk and reliability issues, and opportunities for reversibility (flexibility) and rehabilitation (Kundzewicz, 1999).

Concluding remarks

There have been many recent events of damaging abundance of waters in urban areas in Poland. River floods constitute an important category of problems. Large floods can be caused by large rivers, the Vistula and the Odra and their tributaries, in particular headwater streams conveying waters from intense rain in the southern, highland part of the country where precipitation is typically higher than in the rest of, mostly lowland, Poland. Another category of problems are inundations caused by intense precipitation on urban areas (e.g., 50-100 mm of rain in an hour or two) that cannot be conveyed by the existing storm sewerage systems. The waters inundate streets (paralyzing communication) and pour in into cellars and underground pedestrian crossings. Urban drainage is not adequate to changing land use (and resultant changes in water storage, runoff coefficient, and roughness).
Occurrence of the following situations of complex (multi-mechanism) flooding in Polish conditions, inundations can lead to particularly severe flooding (Kundzewicz et al., 2012b):

- Flood wave on a tributary coincides with a flood wave on the main river.
- Intense rainfall occurs during snow melting.
- Intense rainfall occurs in urban areas during passage of a flood wave on a river.

As stated by Smith & Ward (1998, p. 5) *floods constitute a « hazard » only when human encroachment into flood-prone areas has occurred*. Indeed, for the nature floods are typically more a blessing than a curse – they recharge aquifers, providing abundant water to ecosystems.
Consequences of the inherited non-sustainable land management can be overcome if humans move out of harm's way. When adequate flood protection cannot be provided, permanent evacuation of floodplains is a viable option that definitely belongs to sustainable development.
Which flood protection measures are sustainable for sure? No doubt that *source control* and *soft* approaches belong to this category. However, this is not sufficient as a remedy against extreme floods and, in particular, urban flooding. Despite the criticism of structural flood protection measures, they are absolutely indispensable in order to safeguard existing high-value developments (including historical and cultural heritage) in urban areas. An effective flood protection system is therefore a mix of structural and non-structural measures.

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