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Flood Protection in Urban Environment

Flood protection – some basics of flood protection

Flood management – flood protection or flood control – has been changed in the past decades. Global challenges, such as climate change and the increasing human population, revealed the demand of change in our approach to floods in the frame of global water management. The World Meteorological Organization, as a non-profit professional organisation and the Global Water Partnership, as an open international network of organisations involved in water resources management, developed the Associated Programme on Flood Management (APFM). The APFM promotes the concept of Integrated Flood Management (IFM) as a new approach to flood management [1].

The traditional response to severe floods was typically an ad hoc reaction. It covered a quick implementation of a project that considered both the problem and its solution to be self-evident, and that gave no thought to the consequences for upstream and downstream flood risks. The flood management practices have largely focused on reducing flooding and reducing the susceptibility to flood damage. Traditional flood management has employed structural and non-structural interventions, as well as physical and institutional interventions.

The main tools of flood control are divided into two groups in the last decades. These two groups are the structural and non-structural tools, or measures. According to the definition of the United Nations Office for Disaster Risk Reduction (UNDRR), the structural measures are any physical construction to reduce or avoid possible impacts of hazards, or the application of engineering techniques or technology to achieve hazard resistance and resilience in structures or systems. The non-structural measures are measures not involving physical construction which use knowledge, practice or agreement to reduce disaster risks and impacts, in particular through policies and laws, public awareness raising, training and education [2].

These interventions can be applied before, during and after flooding, and can often overlap. The traditional flood management interventions are the following [1]:

- source control to reduce runoff (permeable pavements, afforestation, artificial recharge)
- storage of runoff (wetlands, detention basins, reservoirs)
- capacity enhancement of rivers (bypass channels, channel deepening or widening)
- separation of rivers and populations (land use control, dikes, flood proofing, zoning, house raising)
- emergency management during floods (flood warnings, emergency works to raise or strengthen dikes, flood proofing, evacuation)
- flood recovery (counselling, compensation or insurance)

https://doi.org/10.36250/01052_14

The IFM covers land and water resources development in a river basin, within the context of the Integrated Water Resource Management (IWRM), and aims at maximising the net benefits from the use of floodplains and minimising loss of life from flooding. The IFM treats the river basin as a dynamic system in which there are many interactions and flux between land and water bodies. In the view of the IFM, the starting point is the river basin and the sustainability of its livelihood, looking for identifying opportunities to enhance the performance of the system as a whole.

An Integrated Flood Management plan has to address the following six key elements that follow logically for managing floods in the context of an IWRM approach [1]

- manage the water cycle as a whole
- integrate land and water management
- manage risk and uncertainty
- adopt a best mix of strategies
- ensure a participatory approach
- adopt integrated hazard management approaches

It is important to determine the role of water engineer in the context of IFM, since this concept points beyond the usual engineering way of thinking. There are several points of IFM which requires the collaboration of representatives of several professions, as economists, environmentalist, etc. Further on, the engineering aspects of flood management – with special regards to the urban flood management – will be presented.

Flood protection, or better to say protection against inundations, evolved parallelly with the development of technology. The first protecting technology was the careful selection of housing places, where the inundations could not occur, or the frequency of inundation was tolerable.

The second step of flood protection was the use of some intervention to achieve this aim, so filling up territories, mainly with limited extension, focusing basically on the buildings.

Later, the territorial flood protection has been achieved using engineering solutions, dykes, as the economic development made it possible. This solution was applied only if the protected territory could be used for some intensive production with high income. An unfavourable change of the flood regime was observed, caused by human interventions on the water courses and climate change issue. The exposition of social values to floods increased gradually, the engineering solutions of flood protection seemed to become more expensive and their unfavourable environmental effect was recognised. This process has caused the change of approach, in addition to the engineering solutions, other considerations emerged, as local protection, building protection, flood tolerable building technologies, or education for increasing the resilience of the society.

Urban flood protection shows similarly a development, but there are other considerations as the consequence of the urban environment. Principal characteristics of flood endangered urban environment is the a quite intensive land use, as traffic area, habitation or recreational area, zone of industry with ports etc. Because of this often shared, multiple purpose usage. To fulfil the increasing increased demand for complex solutions the engineering tools must not be used exclusively. The complexity of these facilities demands most of the cases unique solutions and strong collaboration of engineers, architects and landscape designers.

The public utilities which are inevitable parts of urban environment give an extra problem to face with during the realisation of urban flood protection. These utilities are generally underground structures, pipes, cables, and their manholes, and other special facilities. This environment is rather unusual and sometimes dangerous for the flood protection facilities, since these have to be waterproof and resistant for the effects of seepage.

It is important to mention that flood protection in general – and especially in urban areas – is composed of two basic elements. The first is the protection of the surface from direct inundation, making temporary dikes, raising the crown of levees. The second element is the collecting and pumping of water – waste water, or rainwater, or seepage water – from the defended territories. These two key activities are the basis of flood protection.

Characteristics of urban environment

The urban area can be characterised with high population density and infrastructure of built environment. According to the World Bank data, 54.8% of the human population of the Earth lived in urban areas in 2017. This percentage was 33.6% in 1960 [3].

The higher density of people inhabitants – over the personal properties – results in the a higher density of urban assets, public and company wealth. These facilities together ensure the continuity of the extremely complex process of value producing in towns. However, these assets can be rather sensitive. Any disturbance or blocking of their operation can cause extremely high damages. Because of this characteristic, the urban areas considerably exposed to any disasters, so as the floods, which causes hazard for human life. These events can cause physical damages of facilities or further indirect damages, by the consequence of blocking the normal way of urban value production. This vulnerability needs to be diminished to the lowest possible level.

The main types of flood damages are:

- loss of human life, or injuries (physical and/or psychological)
- harms of structures of several facilities in the inundated area
- harms of devices, fixtures of facilities (electronic devices, furniture, etc.)
- contamination of inundated area (flushed hazardous chemical substances, bacterial contamination from sewers or landfills, etc.)

The potential damages can be diminished by the following strategies:

- prevention, building of flood protection structures, raising the low-lying areas, avoiding construction in frequently inundated territories
- prevention by active flood protection, use of local protecting tools, demountable structures
- wise use of buildings, deploying water sensible devices on upper floors

The specific environment of towns means limitations for the above-mentioned interventions. These limitations are:

- built-in areas
- subsurface public utilities
- disturbed "urban soil" with high seepage capacity
- underpasses, subsurface premises
- continuous surface traffic, logistic difficulties of supply of flood protection works

Built-in areas. In order to understand the difficulties of urban flood protection, the previously mentioned limitations are needed to be explained in more detail. These circumstances can be better understood with some view to the development of towns.

Regarding the development of towns, two different ways of development can be identified. The first is the slow, organic way of development, the second is the fast growing of cities, properly from nothing.

Organically developing towns had sufficient time to suffer from flooding during their life. Some cities had thousands of years of development; this time span was enough to gain fundamental experience of weather and flood extremities. The chronicles, water level records has showed extension and level of flood events for later generations, and so the strategies were developed to prevent the harms. The prevention means the careful selection of built-in areas, shunning the frequently inundated regions and preferring the higher areas. Another way of prevention can be the well-chosen building technology, as using piles, leaving the bottom floor to be inundated in the case of floods, and so on. During the development of these cities there was a continuous attention to the flood issue; so on the frequently inundated locations:

- the buildings are less sensitive to flooding
- the areas would be raised to a secure level
- the areas are defended by dykes

The example of this process can be seen in historical floodplain cities. E.g. in case of Budapest, the Danube floods destroyed the assets on the floodplains in 5–10 years mainly by ice jam caused floods. This was strongly ingrained in the inhabitants, so the old towns were built on the isles of the floodplain, a few meters higher than the average terrain of floodplain, over the frequent flood levels. Later the city began to grow and the inhabitants had to confront with the question of floods. After the devastating flood of 1838, the community of the city decided to build flood protection facilities, raised the territories to a more secure level by the river, built dykes making a continuous defence line between the floodplain isles, raised areas and the high banks (the natural banks of rivers are higher than the frequent or admitted flood level). These solutions worked well enough until the change of the flood regime, which was caused by the meteorological variability and/or the change of runoff regime. As a consequence of these changes, previously safe parts of the town became endangered again. There are historical parts of the city that are more frequently inundated during floods in the recent decades.

The towns which develop rapidly within decades do not have historical experiences of floods. The flood exposition can be underestimated easily.

Subsurface public utilities. The densely built-in areas are supplied with water, gas, electrical and communication utilities which can drive the water toward the lower areas of towns. The density of conduits can be extreme, as it can be seen in Figure 2. The public utilities make the urban area penetrable for water, sometimes independently of the surface level. It means that if there are some water conducting utilities (not only water utilities but also cable ducts of electrical or telecommunication conduits) they can take the water behind the higher level territories, causing the inundations of cellars or deeper parts of the surface. Therefore, the ducts of cables need to be interrupted by sealing. The unserviceable not removed ducts have similar danger.

Figure 1. Density of public utilities in urban environment (Budapest Sewage Works)

Disturbed "urban soil" with high seepage capacity. In urban territories, the soil was moved several times as the built infrastructure developed and as the surface was transformed. In most cases there are so-called "culture layers" over the natural or original sediments or bedrock. These soils are composed by the remaining materials of buildings which were used for the foundations of roads, or simply filling materials. The filling materials can contain mainly pieces of bricks, blocks of stones, debris, sand, gravel, clay, humus and of course air. These ingredients are characteristically mixed in these layers and so the mechanical and hydraulic parameters of these layers spread unpredictably. At the planting holes of trees by the sidewalks and roads, which can cause problems during a flood similarly the before mentioned situations, by secondary flood phenomena frequently. If the groundwater pressure is significant, in a lower territory near a dyke, the "urban soil" layers can result in produce sand boiling and with flushing out of the fine ingredients of soil. These processes can occur problems in buildings from inundations of cellars to load-bearing decrease of the foundation.

Underpasses, subsurface premises. The subsurface premises, underpasses, subsurface railroads or other transport tunnels can conduit a high rate of water farther from the river. The underpasses can open the way for the flood to get to metro tunnels. The protection of these objects is highly important, since the flooding water can have an almost infinite amount of supply in several cases.

Continuous surface traffic, logistic difficulties of supply of flood protection works. The flood control activity presupposes a highly organised logistics, especially if the flooding is very intensive. As will be shown in the next section, there are several types of floods. Their character is different, depending on the flood level, the intensity of water level change, or the discharge of the flooding river or watercourse, the supply of the flooding water. The technique of flood protection work determines the logistical demand, as well. If there are steady built facilities – dykes, walls – with the specified necessary height, cross section and material, the logistic demand is limited to the supply tasks of interventions against the secondary flood phenomena, so i.e. the sand boil or leakage. These require fast intervention, but this is relatively rare in urban environments. The occurrence of secondary flood phenomena is random-like. It depends on the ever-changing urban environment. For example, the seeping water can break into a building site, or the ducts of public utility can be the source of a local inundation, the surface can collapse after the seeping water flushed the soil into the sewer on an unknown hole or discontinuity. The fight to repair these situations supposes a certain kind of "guerrilla fight"; the errors appear unexpectedly, in the living urban environment, which requires the fast reaction and fast transport of defence defence materials.

Typology of urban floods

Several types of floods can threaten the towns, depending on their geographic situation.

Every town is exposed to rainfall caused floods, these can occur even in a desert environment. The heavy rainfalls can cause flash floods if the topography is favourable for the concentrated runoff.

Towns were generally deployed near water, let it be sea or river or lake. The vicinity of waters has various advantages, ensuring potential source of drinking water, transport route or crossing point for interregional trade, technological water source for some industry, and mainly in ancient times it could have defence value as an obstacle. On the other hand, the proximity of water is a disadvantage to these towns, regarding the floods. Some types of floods can be the result of human activities, industrial processes.

The flood exposition depends on the geographic environment. The vicinity of sea and lake can be the source of coastal floods. The relevant relative relief in the urban areas or upstream of urban areas may cause flash flood exposition. Greater rivers can cause river floods with longer duration and large – quasi infinite – volume of water to retain between the levees. Artificial lakes, reservoirs can be the source of reservoir floods, which can be related to meteorological events, but also to structural malfunction or rupture, or structural fatigue.

Pluvial (surface water) flooding

Pluvial flooding occurs when an extremely heavy rain exceeds the capacity of the drainage systems. In this context, the drainage capacity covers the infiltrating capacity of the earth, the retention capacity of surface objects, ponds, and the hydrological capacity of the rainwater drainage system. The pluvial flood is a territorial threat, the flood protection is spatially distributed, while other types of floods can be characterised by lines (e.g. levees) where the inundation can be blocked.

The drainage capacity is variable in time, it depends on the present instantaneous state of the soil, the filling status of ponds, the wetness of the surface, and the free capacity of the drainage system (was its capacity exhausted during a previous rainfall, could debris jams block the drainage process in the drainage system). From the point of view of pluvial floods, the most relevant kind of precipitation are the cloudbursts, thunderstorms, when the intensity of rainfall can exceed multiple times the design intensity of the rainfall drainage systems. In well drained towns, the critical rainfall intensity of possible occurrence of pluvial flood exceeds 35–45 mm/h in a 10–20 minute time span (it means at least 97–125 l/(s.ha) average intensity). The critical intensity rainfalls are connected to convective atmospheric currents.

In the temperate climate, the duration of critical rainfalls is generally very limited. The convection is driven by the heating of the Sun or frontal situations, or the orography, so generally nights can block the convectional currents in the atmosphere, or the fronts are moving fast. There are exceptionally long-lasting thunderstorms, supercells which can remain active more than one day, but characteristically they move with the regional currents, so a certain territory can be covered by the storm cloud only for a few hours. In mountainous regions rainfall can be extremely intensive.

In tropical and subtropical territories, enormous rainfalls occur regularly, which can last for several hours or some days. The tropical storms are regularly driven by the heat stored by the sea, and so over the sea the convection can be continuous in the night hours as well. The sea continuously supplies the storm with water. This can result in extreme rainfalls in the hurricane, monsoon and typhoon zones, or in the archipelago of tropical or subtropical seas.

Table 1. Some extreme intensity values from the world [4]

Duration (min)	Precipitation (mm)	Intensity (mean) [l/(s.ha)]	Place	Date
1	38.1	6,365	Guadeloupe	26.11.1970
1	31.2	5,200	USA Unionville (MD)	04.07.1956
15	198	2,200	Jamaica	12.05.1916
20	205.7	1,714.2	Romania, Curtea de Argeş	07.07.1889
42	304.8	1,209.52	USA Holt (MN)	22.06.1947
60	401	1,113.9	China, Shangdi	03.07.1975

Duration (min)	Precipitation (mm)	Intensity (mean) [l/(s.ha)]	Place	Date
60	305	847.2	USA Holt (MN)	22.06.1947
60	305	847.2	USA Kilauea (HI)	24–25.01.1956
360	840	388.9	China, Mudocaidoang	01.08.1977

Table 2. Some Hungarian extremities [4]

Duration (min)	Precipitation (mm)	Intensity (mean) [l/(s.ha)]	Place	Date
10	64.2	10,700	Zirc	24.05.1915
60	120	333.3	Heves	23.08.1988

The character of pluvial floods depends on the topography of the territory. If the relative relief is higher, the pluvial flood becomes similar to flash floods with high velocity and locally concentrated damages. The plain territories suffer from inundation depending on the micro topography which can fall in the range of decimetres.

Rainfall is the most variable meteorological phenomena both in time and space. The spatial distribution of rainwater depends on the extent of the storm cloud, and the direction of its motion. In the temperate climate, storm clouds are typically a few kilometres in size, sometimes reaching or exceeding 10 km in diameter. Even under a storm cloud, rainfall is variable, so the heaviest rainfall is limited only for a 1–2 km zone. It means that some parts of the given urban area will be hit by the heaviest rainfall, and the damages will show a certain concentration. In the temperate continental climate, extreme rainfalls are not frequent, in a person's lifetime it occurs only 3–5 times in a certain place. The phenomenon takes place very fast, the forecast practically does not work, the so-called nowcasting can ensure the relevant data but only for a very short time, so the civil defence forces cannot be at the field in time, because the rainfall happens in short time scale. The mitigation of these factors is very difficult, the people (and civil defence forces) cannot intervene; in these cases, preparation, individual initiative and problem-solving capability is of primary importance.

Based on these characteristics, the defence tools of the pluvial floods can be determined. There are two stages of flood prevention:

1. Determination of rainwater courses (and its parameters as velocities, depth), and the probable extension and depth of inundation. These results can be determined by runoff models.

2. Determination of flood prevention tools for the present and future buildings and land use.

The flood prevention tools for pluvial floods have to be:

- quick to assemble, simple structures to be built up by civilians
- easily storing kits
- trained civilians for the mounting of basic protection tools and kits

During extreme rainfalls, preventing loss of lives is more important than the protection against inundation.

Combined Sewer Overflow (CSF), the sewage appears in cellars, or on surface

If the rainfall drainage is solved by a combined sewer, the CSF causes biological contamination on the terrain, or directly in flats where the water can get in. Although the sewage becomes highly diluted by rainwater, the polluted water can still cause diseases, and it can be source of epidemy. If the rainwater drainage system is separated from the sewage, the water can be contaminated by the flushed pollutants and waste, and can cause health problems similarly to diluted sewage. The CSFs can be prevented using:
- adequate capacity canals to take the water away (it is an economic and technical question)
- correct hydraulic design to diminish losses
- well prepared system to operate even under pressure, so the diluted sewage cannot get out from the sewer through manholes, gullies and household openings (rainwater should also not enter into the combined sewer until the pressure does not decrease into an adequate level; this problem has to be treated by storage tanks)
- preventing sewage backflow with automatic plugs, butterfly valves in household lines

Surface inundation can occur as a fast or a slow-moving current, or can be a temporary pond too. The inundation threatens the cellarage and low floors of buildings. The flooding can cause significant damages in these parts of the buildings, like underground parking floors, but even electric transformer units, surgery rooms of hospitals, archives in record offices, etc. can be affected in this way. The closing of these parts of the building can be managed with light metal beams, flood doors and gates. The height of the structure must be at least the probable highest level of water. The highest water level can be determined by modelling or empirically (based on experience or wise precaution).

Flash flooding

Flash floods are the result of heavy, extremely intensive rainfalls on the catchment area of smaller rivers or ditches. The phenomenon can occur in areas characterised by high relative relief, it supposes hillsides, mountainous territory. Because of the steep surface, the time of concentration is rather short: it takes a few tenth of minutes or a few hours in few 10 km^2 catchment areas exposed to the cloudburst, and as the exposed territory grows to 100 km^2 the time will be longer.

Generally, the flash floods can occur more frequently if the runoff coefficient is high, and beyond the high fall, the surface cover is scanty. However, flash flood occurs in forested area as well, since the water retention capacity of the vegetation, soil and terrain can run out if the rainfall intensity and volume exceeds a certain threshold. In this case the frequency of flash flood is rather low, and occurs only with quite extreme rainfalls.

Reduction of flash flood effects can be achieved if the runoff can be slowen significantly in the upstream valleys.

The characteristics of occurrence of flash floods are very similar to the pluvial flood event, since the flash flood is the consequence of extreme rainfalls, so the main considerations are related to this phenomenon. Flash flooding is related to convective rainfall activities (supercells and other cloudbursts). The extreme rainfall intensities cause the extreme peak of discharge. The possibilities of forecast of flash flooding are similar to the cloudbursts, these can be early warning signals from real time measurements or estimates, produced based on:

- remote sensing devices (radar, high spatial and temporal distribution "miniradar")
- network of rainfall measurement devices (datalogging rain gauges with nearly real time data communication unit)
- water level detecting unit (ultrasound surface detecting, pressure detection in riverbed, etc.)
- automatised picture analysis to recognise the flood' appearance in the riverbed

The earliest signal can be earned from the rainfall detection. The most direct solution is the water level detection. It can be operated as a part of an automatic early warning system. The success of detection must be independent of perpetuated circumstances of flash flood. The device must be mounted within a secure distance of the flooding water. This is important, because devices immersed into the flow can be teared off and taken away by the high quantity of transported materials. The nowcasting can be gained from real time measurement of rain depth and simultaneous high resolution radar observation of cloudbursts. The rainfall radar can give spatially continuous estimation of rainfall intensity distribution. The technical solutions of the radar estimation and the connecting technical and theoretical problems are discussed in several studies [5]. Here it is important to mention that the radar cannot measure rainfall intensity directly, it measures the reflection of the radar beam on raindrops or pieces of ice in the storm clouds, so there can be significant differences of estimated rainfall and the quantity of rain reaching the earth surface. This uncertainty can be eliminated by using field measurement units. However, there are several sources of errors of field rain gauges, the field measure of rainfall is an essential tool of the refining of radar data. If there are more rainfall gauges close to each other (within 2–5 km) the radar data can be used as an estimation of rainfall distribution between the two devices.

Flash floods can have a triggering effect on another dangerous phenomenon, the debris flow. Debris flow can occur if some particular conditions come together, such as a steep slope of the valley, the flushable material is in enormous volume (5,000–30,000 m^3/km^2), and the water wets this material and lubricates the moving mixture (precipitation and/or waterflow). In case of a debris flow, water has a special role, it works as a lubricant between the rocks, wood pieces and mud; sometimes it looks like the fresh wet mixture of concrete. The debris flow is not a Newtonian fluid, it has special characteristics. It can move very fast in steep valleys (0.5–40 m/s), but if the sloop of the valley diminishes under a threshold value (2%), the transported material stops and the mud and stone mixture can cover the bottom of the valley in several metres of height [6]. Debris flow can occur without atmospheric trigger effect, the root cause can be volcanic eruption with melting snow, or human activity such as reservoir catastrophe. The question of debris flow has been studied first of all in countries that are particularly vulnerable to this kind of disaster by their geographical and meteorological environment.

Defence against flash floods is very difficult. Due to the rapid character of the flash flood, the rapid runoff and unexpected water level rising, cause that operative flood control cannot be successful. There is no time to build defence lines to salve riverside territories.

The best solutions are the structures which have continuous defence capacity (structures), or those which can be deployed very fast, or which are well prepared, well designed, and well armed against the extreme effects of flash floods. These extreme effects are:

- extremely fast rising of the water level
- extremely high velocity
- presence of masses of sediment
- significant mass of transported debris

The quick to assemble structures can be applied for the defence of solitaire buildings, for closing gates, doors and windows of the given facility. There are several products for this aim, which use the following schemes:

- removable flood barriers
- flip-up flood barriers
- drop-down flood barriers
- self-closing flood barriers

The technical part of the prevention is some built flood prevention solution, such as a flood protection wall or some levee. These structures are always prepared to the flood protection, at least to their defence capacity (height, resistance of seepage, etc.). Over the usual construction rules of these structures related to the defence level and seepage, some further circumstances must be considered, as the extreme velocity of the currents and the effect of probable collision of heavy floating objects, tree trunks or other things of significant dimensions. Such flood prevention constructions become the part of the landscape. These structures will have a role only in cases of flash floods, so only for short times and rarely, during their expected lifetime. It is essential to find an optimal use and aesthetics for these structures for the time when there is a normal hydrological regime. The realisation of this aim can be achieved by careful design with the collaboration of landscape designers and architects.

The second part of the prevention is the forecast and early warning system of the local flood protection service. The problem is similar to the pluvial floods: the phenomenon is related to very intensive, extreme rainfalls which can be characterised by quickly changing rainfall intensities and fast moving rainfall fields.

Coastal flooding

Coastal flooding occurs in the vicinity of lakes and seas. This kind of flood is caused by extreme tidal conditions including high tides, storm surges, seiche and tsunamis (the duration is in dimension of hours or days).

The flood defence facilities of coastal cities are planned on the basis of water level observations of the given lake or sea. Due to the climate change, there are predictions of increasing number of storms and tempests. The importance of coastal floods is increasing with the rising and forecasted rising of sea level all over the world. The summary of these factors is that the frequency and seriousness of coastal floods will increase rapidly. There are several examples of more frequent coastal flood issues. Some of them happens parallelly with the sinking of the coastal territories, as in Venice, or in Jakarta. In other regions, the river' estuary areas are threatened, as in London. In the Netherlands, complete regions are under average sea level, where the stormy tide jeopardise the lives and economy. Similarly, in the case of New Orleans, the low coastal region was destroyed in the extreme hurricane Katrina, which caused the backwatering in the estuary region of the Mississippi, beyond the heavy rainfalls. Some of these issues can be handled with flood gates which can be closed during the high tide to save the cities and their outskirts at river mouths. These kinds of facilities can be found in Rotterdam [7] and London [8].

Figure 2. Maasdijk, tide gate at Rotterdam [7]

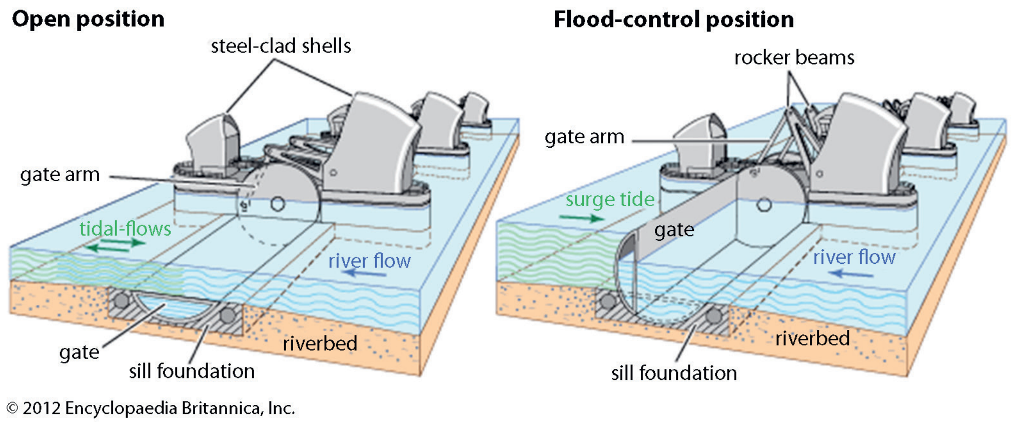

Figure 3. Thames barrier, London – Functional sketch [8]

Lakes show similar threats, only the rising level of lakes is not in direct relation with the global changes in all aspects, and – contrary to seas – the water level of lakes can be regulated in most of the cases. As the water level is regulable, if the meteorological regime changes, the regulation should be overviewed and reshaped. The motion of the waterbody and the flooding at shores of a lake can be caused by:

- surplus water
- wind
- geological processes

The duration and development of these phenomena is significantly different. The surplus water caused elevation is the function of the arriving water volume. The water level elevation depends on the intensity of appearing of surplus water, the free storage capacity of the lake, and the natural or artificial (sluice dams or sluice canals, tunnels, etc.) overflow capacity. The development of floods caused by surplus water in lakes depends on the characteristics of the catchment area and the free storage volume of the lake, over the normal water level. If the storage volume is pretty great comparing to the possible extreme runoff arriving the catchment area, the coastal flood develops relatively slow, the process can take days, or weeks. The success of intervention depends on the regulatory capacity. But, a stormy weather results in inconvenient surprises.

Floods caused by wind are the result of waves higher than the lakeshore and the phenomenon seiche. The harm of flood is heavier if the water level is higher from the beginning, in this case the wind is able to push more water out from the lake. The seiche is another group of – mainly – wind-caused floods. The seiche is a oscillating motion of lakes (e.g. Great Lakes, Leman Lake), semi-closed seas (e.g. Baltic Sea, Nord Sea, Adriatic Sea), harbour basins or smaller artificial basins. The seiche are related to winds, air pressure change, underwater internal waves, and sometimes to seismic activity.

There are examples for deep lakes in the Alps, as the North Italian lakes, Lake Lemon in Switzerland, where seiche was studied for the first time [9]. An example for shallow lake is Lake Balaton, where seiche has been studied since the end of the 19th century [10], and seiche caused by wind has been making damages. The duration of a seiche depends on the meteorological situation and the damping of the pendulum-like motion of the water level; it can take some hours or several days. The range of water level change can reach the magnitude of meters, depending on the shape and volume of the lake, and the intensity of the triggering effect. .

The coastal floods of lakes can be caused by geological or geotechnical catastrophes in mountainous regions, where there are steep instable slopes of mounts over the lakeshore, which can slip or fall into the water. If the volume is extremely large compared to the volume of the lake, the waves can cause accidental inundation. Similar situation can occur if the sediment slips down under the water level if there are instable slopes. This kind of inundation happened in 509 AD in Lake Geneva. The trigger effect of these motions can be an earthquake, or the wet weather which is favourable for destabilising effects of slopes, as wetting of instable masses, decreasing the shear resistance and increasing the mobilising forces. These phenomena are very similar to tsunamis.

The last category of coastal floods is related clearly to tsunamis. The tsunami is a very long wave which appears when some impact constrains an enormous mass of water to a displacement. The impact can be for example an intensive horizontal or vertical motion of the seabed during an earthquake, a landslide on the seabed, an extreme volcanic eruption, collision of a significant size meteorite etc. The extent of the tsunami depends on the water volume moved by the impact and the intensity of the triggering phenomenon. The tsunami waves become extremely high when they reach the shallow water at the seashore. The height of the wave is also influenced by reflections taken place on the seashore or in narrow gulfs and river mouths. The height of tsunami waves can reach 10–15 metres. The character of a tsunami is on the one hand a rapid and extremely high inundation, on the other hand the high-speed currents of water in the flooded region. The damage potential is enlarged by the floating debris of shattered structures, vehicles, trees; it causes severe injuries and results in a chaotic landscape where finding surviving victims is rather difficult. The defence facilities of tsunamis are typically maritime engineering structures; further details can be found in relating books and papers. Some examples for well documented tsunamis of the past decades are the tsunami of the Indian Ocean on 25 December 2004, killing 230,000 people in fifteen countries, or the 11 March 2011 tsunami in Japan, causing severe damage also in a nuclear power station, and caused the death of more than 20,000 people.

Fluvial (river) flooding

Fluvial flooding occurs – as a general case – when water level of rivers exceeds or the water breaches the levees during a high-water period. Comparing the phenomenon to flash flooding, the flooding intensity of river flooding is characteristically lower, and the spatial extension of flash floods is mainly located to shorter river branches in narrow valleys, while the river flood affects a longer reach.

The cause of fluvial floods can be a sustained or intense rainfall or snow melting, or their combination, furthermore, a consequence of some catastrophe, e.g. a reservoir failure. In these cases, the flood depends on upstream conditions.

There is another group of river flooding, which occurs when the downstream reach of the river partially or completely loses its capacity to take the water away because of some reason, let it be the flooding of the recipient or tributary river, ice jam or jam of debris, riverbed sediments. The decreasing capacity of the riverbed can also occur as the consequence of some geological cause, as partial closing of riverbed by sliding of mass of material into the river. This kind of flood happens in mountainous regions, or in case of volcanic activity (lava flows).

Ice jam is characteristic in temperate and boreal climatic zones. Debris and sediment caused floods occur only if there is a huge volume of mobilizable sediment, floating debris (first of all wood) in the upstream; these conditions are given in mountainous regions, first of all. The danger of debris jam is more relevant in smaller rivers, where the arriving floating materials can fill up the cross section of the riverbed easily. The possibility of developing jams is increasing with the sinuosity of the river.

The forecasting of the above-mentioned floods differs on their types: the upstream water related floods have generally hydrologic causes, so their forecast can be ensured by hydrological-hydrometrical tools. The debris and ice caused floods are partially dependent of hydrological circumstances – however, these phenomena can occur characteristically parallelly with high water or floods –, the experience of previous cases is important in the preparation phase of the flood protection. In the further part of this section the upstream water related floods will be characterised.

The characteristic duration of river floods depends on a series of factors, such as:

- water supply and volume of flood wave
- slope of the river reach
- length of the river upstream

The water supply and the water volume of a flood wave increases the length – or duration – of the flood, the duration of the period of certain high water levels. A greater catchment area can be supposed if the upstream river reach is long, because a great basin supplies the flood waves. The rainfall origin floods of rivers are induced by intensive, long duration (magnitude of days) rainfall. The characteristic duration of flood inducing rainfall depends on the extension of the catchment area. If the catchment area is smaller, shorter and more intensive rainfalls cause floods; as the area is increasing the characteristic duration becomes longer.

In the case of River Danube, the long duration intensive rainfall of the upper part of the catchment area causes floods in the May–August period. This kind of floods caused extreme floods in the 2002–2013 period with relevant or extreme peak levels in several gauges of the Hungarian section Danube. Another kind of flood is induced by the snow melting in the Alps, in the March–April period. The snow melting combining with rain can cause extreme high water levels, as it happened in 2006. Earlier, the ice jam caused floods occured frequently on the Hungarian reach of the Danube, but it has not occurred since the 1956 spring flood as a result of the river control interventions, and the continuous ice breaking to prevent the formation of ice jams (Figure 4). On the downstream reach, in Serbia, Bulgaria and Romania the formation of ice jam can be a real danger even today, as it happened in the winter of 2017 [11]. The local effect of the global warming diminishes the occurrence of ice and the probability of ice jam caused floods.

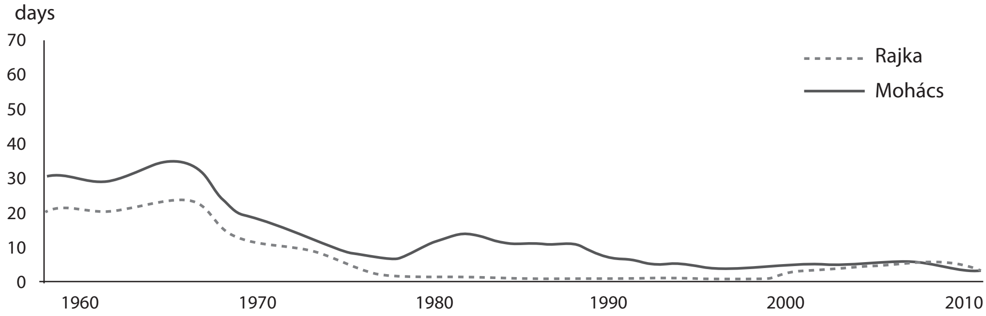

Figure 4. Changes of the average length icy period of the Danube between Rajka and Mohács in Hungary (10ys moving averages, 1958–2011) [11]

Reservoir flooding

Reservoir flooding occurs when a reservoir' dam failure takes place, and the stored water appears abruptly in the low-lying areas in the downstream of the dam. The flood takes places in a short time (few hours), but regarding the volume of the outflowing water, the intensity of the flood is often extreme, the effect of this kind of flood is devastating.

Hydrological, structural, geotechnical and geological factors can cause reservoir floods. During the lifetime of a reservoir, extreme hydrological events can occur which can overload the dam the spillway. Based on the short hydrological time series, the determination of the incoming discharge could not be exact enough, so for less frequent events the under-dimensioning of spillways could have happened. Also, the climate change can influence unfavourable the change of hydrological regime, which can favour the more frequent occurrence of extreme rainfalls. The dam failure can take place as a consequence of geological catastrophes, landslides, earthquakes. The Baldwin Dam collapsed in 1963 because of geological, geotechnical and structural problems and caused the death of 5 people (Figure 1).

Figure 5. Reservoir flood in Los Angeles, 1963 (http://damfailures.org/case-study/baldwin-hills-dam/)

The effect of a dam catastrophe can be aggravated if the stored liquid contains some industrial waste. There are technologies of the mining and ore processing industry which uses highly alkaline substances, or other poisoning materials for the extraction of metals from the ore, in an enormous volume. In the past decades, there were two devastating dam catastrophes related to liquid industrial waste storage reservoirs in Middle Europe. On 30 January 2000, 100,000 m^3 cianid containing sludge got into one of the tributaries of the Tisza River in Romania after a fast snow melting and rainfall which caused the flushing of the dam of the sludge reservoir near Baia Mare. On 4 October 2010, a poisoning liquid side material storing reservoir' dam collapsed in Kolontár, Hungary, because of the unusually much rain caused overload of the dam.

Flood protection facilities in urban flood control

The flood protection of the urban territories against the flood types mentioned in the previous sections is quite different and very similar at the same time regarding the defence methods. The difference can be determined in the time of development and the duration of the given flood threat, i.e. the possible timespan of operative flood protection. The timespan is important from the point of view of organisation of flood protection capacities (personnel and technical conditions).

The flood protection against pluvial floods concentrates mainly on the drainage capacity and inundation control. The process of pluvial flood takes several days, and a few hours, one or two days in extreme water level range. The direct inundation and seeping water can cause damage, and the seeping water can do it alone too. The water seeps or flows to the places where the water's energy level is lower. By seeping the groundwater's level rises, and threatens subsurface facilities, cellars and terrain depressions. A successful flood defence means a continuous control of groundwater and seeping water parallelly with the prevention of direct inundation. The same is true for rainwater control during floods, since the recipient of the rainwater is the flooding river, and the high water level of the river demands the rainwater to be pumped.

During rainfall, high volume of water appears in towns, inducing a runoff process. If the runoff exceeds the capacity of rain sewers, the water flows on the surface, and inundations occur. In case of combined sewers, it is extremely problematic, because it causes the overload of wastewater treatment plants, and in most of the cases, the overflowing water takes the pollution directly into the recipient. To prevent this, the separation of rainwater must have a priority, and the increase of sewer capacity or the retention or use of rainwater is to be solved. The most characteristic way of protection against floods caused by rainfall is rainwater drainage. The enlargement of sewer capacity is quite expensive. The paved surfaces of towns and the tendencies of climate change often provoke lack of water, therefore, rainwater harvesting must be provided, and only that part of water is to flow away, which cannot be caught, stored, infiltrated, used in some appropriate way. The time of utilization of water does not coincide with the rainfall often, so the storing of water is a critical issue.

Generally, the green solutions can manage the water of frequently occurring rainfall, but the extremely intensive rainfalls demand engineering solutions. The storage can be performed by significantly great subsurface tanks which can be filled up during the extreme rainfalls, and the water can be delivered later to irrigation systems, groundwater replenishing systems, etc.

The flash flood, similarly to the pluvial flood, is a very fast developing phenomenon, so if the forecasting (or nowcasting) can be managed, the flood protection systems have to be built up within a very short time span. Since, the success of operational protection work is low in a short reaction time, the preparation of inhabitants is important; in this way the people can learn the lifesaving and runaway strategy in the case of a flash flood, furthermore the tools of damage mitigation.

Coastal floods can be nowcasted and the protection is generally similar to the solutions of the flash flood control.

Generally, river floods can be predicted at least a day or two in advance, depending on the runoff characteristics of the given river, so there is a longer time window to the preparation of the flood defence system to the flood protection works. For example, in Budapest the preparation period for a flood are 4–5 days on the Danube, based on the data of Austrian water gauges. This is enough time to mobilise the needed materials, machinery and human resources for the operational flood protection.

The successful flood protection generally means two simultaneous tasks. First, the direct inundation must be prevented, secondly, the collected water must be placed into the recipient waterbody. The first part of the tasks can be divided into two groups, primarily defence of territories off inundation, and secondly, defence against the harm effects of seepage (Figure 6). These secondary phenomena take the danger of significant consequences, such as diminishing the shear resistance of soils, augmenting the probability of collapse of some structures, flood protection facility or other buildings. The possible consequences of urban flood are the inundation, rainfall drainage issues, infiltration of water because of harmful seepage into sewers, cellars, underground facilities.

In the case of a failure of flood protection, depending on the severity of the situation, the sav of lives and the localisation of the flooded area are tasks. A well elaborated emergency plan can help the rescue.

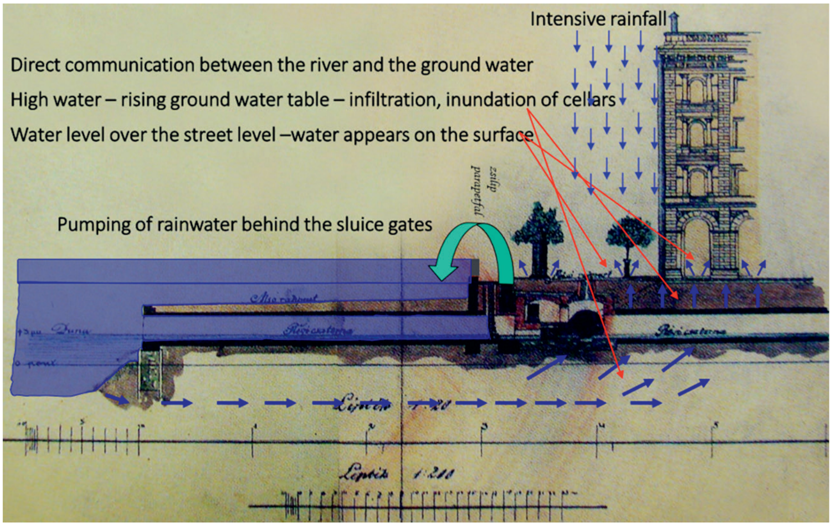

Figure 6. Characteristics of urban flooding [12]

In case of flood control of towns, prevention is most important. Prevention covers structural measures, building of dykes, floodgates, etc. On these structures operative flood protection work can be carried out. The operative work covers the blocking or control of secondary flood phenomena such as harmful seepage, the consequences of the wetting of soil (e.g. the slides of earth dykes or hazardous motion of structures, walls, or the direct burst of water in subsurface chambers, manholes or in the sewers).

The operative measures extend to the building of temporarily structures, as supplementary heightening of structures, building of localisation dykes and defence lines, if a catastrophe seems to be dangerously possible.

A classification of flood protection systems is shown in Figure 7. The basis of the classification is the steadiness of the given structures, determined or not determined building site [13].

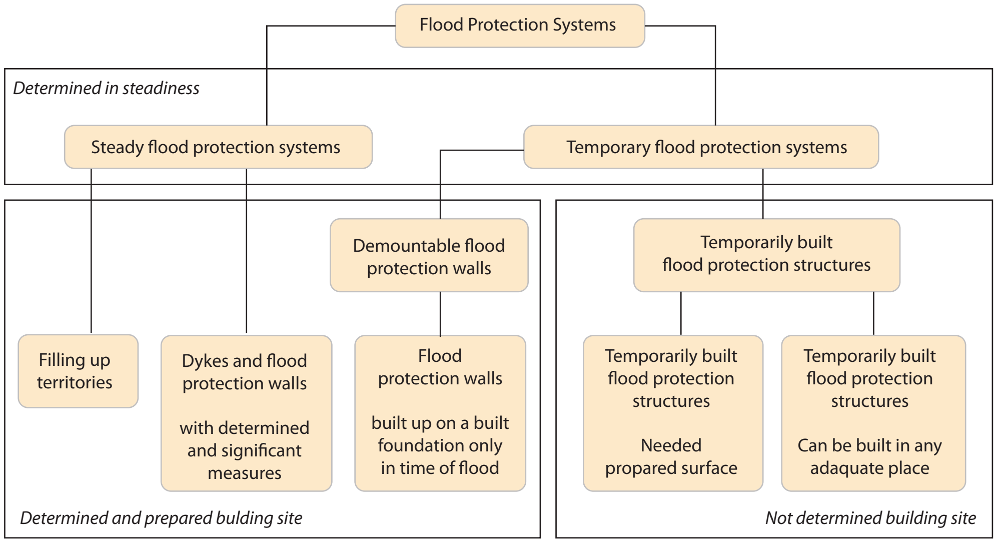

Figure 7. Classification of flood protection solutions (compiled by the author based on [13])

The upper rectangle shows two categories of flood protection solutions, if they are permanent and temporarily built facilities. The bottom left rectangle contains those solutions which are built as permanent facilities, so which effect their defence capacity in a precisely determined place; the demountable flood walls, which are have no permanent defence capacity are in this category since their foundation determines the defence line permanently. The bottom right rectangle contains the two categories of the temporarily flood protection solutions, accordingly to their terrain preparation demand.

The temporarily built flood protection structures are classified into two classes, into those ones which can be utilised in any place which is plain, quasi horizontal and where the load bearing of the earth is sufficient, and the surface is adequate for the secure build. The second class comprise those structures which does not need significant surface preparation before building, as the sandbag wall, for example.

The most secure solution is the rising of the terrain level high enough to prevent the inundation for longer time, hopefully.

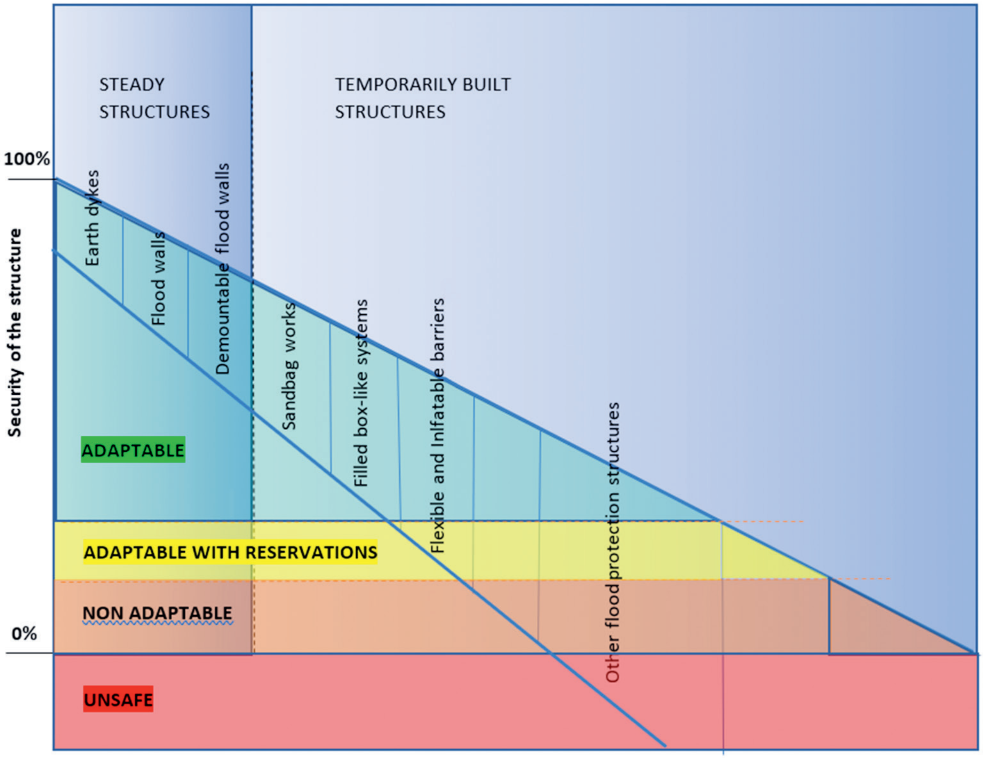

Figure 8. Security rate of constant and temporarily built flood protection structures (compiled by the author based on [13])

The security level of the constant and temporarily built flood protection structures can be characterised on the technical considerations. Figure 8 represents the security level of the widely used flood protection techniques referring to the security level of earth dykes. As Figure 8 shows, the new temporarily built flood protection products cannot reach also the security level of the traditional sandbag based operative flood protection solutions. The inflating barriers fall out the definitely applicable zone, because their security level is judged very low.

The solutions judged less adaptable or less secure, in some cases are not designed prudently, and sometimes there are only promises about their functionality and in practice the characteristics of these products are not proven. The choice of new flood protection products has to be based on static and hydraulic considerations.

Filling low-lying urban areas

Figure 9. Raised street section in Budapest – Veres Pélné street (Google street view)

The inundation and even the secondary phenomena can be prevented by filling up the deep territories of the urban area. It can be simple if the territory which can be flooded is narrow. If the area of possible inundation is greater, the filling can be partial. There are several examples of areal fill up in Budapest. These interventions were made mainly after the 1876 flood when the street level was raised to the flood level, it meant 50-90 cm (Figure 9). After the devastating 1838 ice jam caused flood, the street level was raised at the Pest side of the Danube at the St. Rokus chapel in 1846 (Figure 10). This solution can be economic mainly if the flood threatened territory is narrow, the flood level is not significantly higher than the original surface level, the buildings and other assets of the questioned territory are not sensible to the filling up, their public utility connections remain operable. (A curiosity: the Saint Florian church in Budapest was lifted up by hydraulic jacks by a meter to put an end to the moisture caused damages after the filling up of surrounding territories. The walls at the basement were cut and built again as a supplemental basement structure in 1937 (Figure 12).

Figure 10. St. Rókus Church in Budapest – raised street level at the entrance of the church (Google street view)

Building of dykes

If there is no possibility to fill up the territories or if otherwise impossible, dykes can be built to prevent the inundation. The dykes have some basic disadvantages in urban environment, such as:

- the height of the dyke
- the width of dyke
- a leak in the dyke

Figure 11. St. Florian Church before its lifting of 1 m in 1937 – the street was raised 60–80 cm after the devastating floods of 1838 and 1876 [15]

The significant mass of a bare earth dyke (with its grass cover) can be strange in an urban environment, but if it is inserted into the green infrastructure, it can be an important urban space (Figure 12). The dykes in the urban environment have an aesthetic role as well, their design must be more than the simple water engineering task. Generally, earth dykes can be found generally in the outskirt areas of the towns. In the internal, or intensively used zones of the towns retaining walls, in the case of navigable rivers, wharfs are built. Often the vertical walls are built to gain terrain in the riverside where the lots are generally more valuable. Earth dykes generally disappear with the urbanistic development of the towns. In the past decades, a change in the urban planning resulted in the increasing extension of green zones, following the social demands. The riverside territories are the most available for the fulfilment of this aim, their increasing significance predictable. The application of earth dykes or greened engineering structures are going to be acceptable in these areas.

Figure 12. Earth dyke at the cross section change in Budapest, Pünkösdfürdő in the 2013 flood (Budapest Sewage Works Ltd.)

A general advantage of a dyke is the wide crown, which allows the works to be carried out if some operational intervention is needed during the floods. There is also space for temporary heightening if the circumstances demand this kind of intervention.

Flood protection walls

With the development of urban environment, a strengthening demand for an intensive use of rivers is emerging. This demand is a lot more explicit when the given river is navigable. The complex land use development aims at compelling multipurpose solutions, which can serve further targets beyond flood control. In the past centuries, in many cities the building of wharfs in the downtowns was an obvious demand for the continuous improvement of navigation and other industries. In the past decades, as merchant navigation and mainland logistics have been developed, the ships were directed more and more into well-equipped ports near the towns. In the beginning of this transformation process, the wide storage platforms of wharfs have become urban traffic zones, blocking the citizens from approaching the water, and after this period, the demand to give these sites back to the inhabitants has emerged. These places have been developed into mitigated traffic pedestrian zones, or revitalised riverside spots, serving the inhabitants as part of the green infrastructure. This process resulted in riverside embankment and/or flood protection facilities having new roles.

Flood protection walls are used if the size of the area at the assigned defence line and local land use do not let the building of the greater space-demand dykes. The flood protection walls are a more expensive than earth dykes. The basic expectations are the same, they have to ensure the necessary height, stability and seepage control. Their appearance can be a part of a complex structure, e.g. a 0.5–1 m high wall on a dyke, or the wall can be a stand-alone structure, with a height of 1–3 m. In this last case, there is no often way of further heightening if the water level could exceed its design value in an extreme flood. The walls can be reached from their defended side what can problematic if the height exceeds the 1.5 m. The difficulties are greater if seepage control interventions must be carried out, since in this case the place by the wall is occupied by the seepage control solutions, and the approach of the wall become impossible (Figure 13).

Figure 13. Low flood protection wall, Budapest (Budapest Sewage Works Ltd.)

If the wall is part of a dyke or a retaining wall (so that the flood protection wall serves as a strong heightening of the bottom structure), or the wall stands alone, but its height does not exceed 1.2 m, operative flood protection work can be done in a wider range (Figures 11, 12, 13).

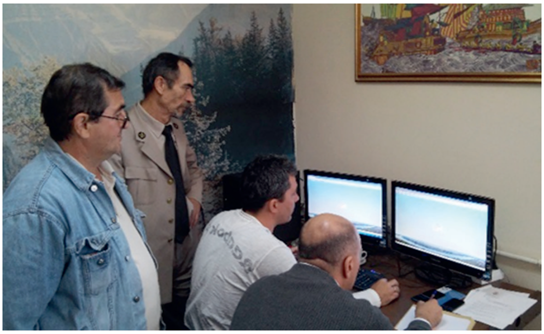

Figure 14. Heightening of low wall with sandbags in Budapest (Budapest Sewage Works Ltd.)

Figure 15. Low flood protection wall as part of a wharf in Budapest – flood control operation in progress in 2013 (Budapest Sewage Works Ltd.)

Figure 16. High flood protection wall, seepage control by counterpressure basin, Budapest, 2013 (Budapest Sewage Works Ltd.)

Demountable flood protection walls

The use of demountable flood protection walls is favourable from point of use of land use. In the valuable urban spaces, the permanent flood protection walls causes continuous obstacle for the normal use, however, the floods generally occur only once or twice in a year, with a duration of some days. This issue can be managed using the demountable walls; their foundation is continuously present, but the structures over the terrain are to be mounted only in case of floods. The reliable forecast of flood is essential, since the construction work with the necessary logistics must be finished before the threshold of the wall would be reach by the flood. If the water is expected to rise faster than the length of the building process of the wall, this solution should not be used. Before the application of the demountable walls, an analysis of the building time to the possible water level rise is to be done (Figure 17) [14].

The success of building a flood protection wall in time presumes:

- a strong, well designed logistic system
- well maintained elements
- well maintained supporting pillars with their connection elements to fix the columns of the structure in any time, even when it is freezing

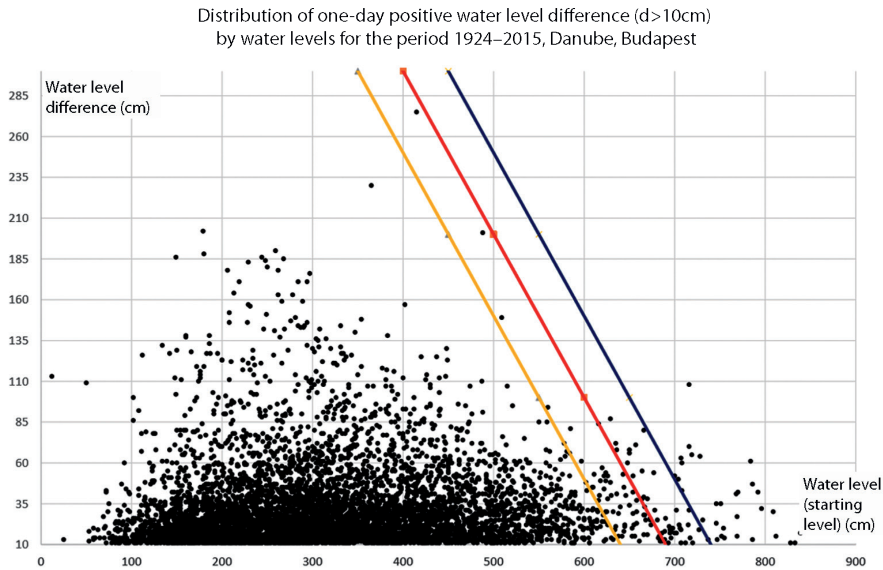

Figure 17. Water level change analysis for one day timespan [14]

This last condition concerns to secure connection possibility on the foundation; the base plates and the anchor bolts must be clean, intact, and defended from vandalism. The organization of mounting work must be planned step to step from storage to the needed spare parts and reserves. These steps are

- storage of the elements (where, how far, loading of elements on lorries, etc.),
- investigation of construction traffic;
- study of the roads' load bearing, width and height, are these adequate for the given lorries;
- how the unload of elements can be carried out;
- is there enough space to deposit the elements, ensure the construction traffic and adequacy of the space left for the building personnel;
- check of for bottlenecks of the transport to determine a realistic building time demand;
- determination of minimum number of installation personnel for the preparation of base plates (counter plates) of columns, mounting of elements;
- determination of the necessary number of tools, scaffolds, ladders, etc.

With the advantages of the demountable flood protection walls, there are of course some disadvantages, as

- sensitivity to river ice collisions, ice jam pressure if the ice phenomena are significant in the hydrological regime;
- the heighten of the structure is not possible, nor during flood, nor if the flood protection capacity is to be risen with the change of law;

- sensitivity to any kinds of vandalism;
- sensitivity to construction time before flood arrives;
- if some relevant elements of the structure do not work in time, or the construction work is delayed for any reason, the defence capacity will not be completed in the required time, and the defence capacity will not be adequate.

Drainage system

The drainage system has a key role to remove the water from the surface and from the upper layer of the earth. The capacity of the drainage system is the function of the current state of the recipient.

If the recipient can receive the water unlimitedly, the capacity depends on the hydraulic characteristics of the drainage sewer. These characteristics are related on the flow characteristics of the conduits (friction loss and local losses), and the water swallowing capacity of gullies. Generally, the gullies swallow the frequent rains, but for extreme rains these are not sufficient.

If the recipient is the flooding water body, the receiving capacity is often limited. In this case, the sewer's collected water must be pumped into the flooded water body. The collected water origins from the rainwater, infiltration, and local inundations. In this case, the pumping capacity has the key role. As the collected water cannot enter into its recipient by the gravity, the sewer must be closed by a sluice gate and a pumping facility has to be put into operation.

In greater sewers, the pumping capacity is ensured with built-in pumping stations, while in the case of smaller canals the pumping can be solved in temporary solutions, using fast deployable diving pumps in the manholes. If there is no built-in sluice gate, shutoff plugs can be applied to close out the flood from the sewer. The temporary pumping site is arranged similarly to the sewer bypass pumping. The pumping capacity has to be harmonised with the drainage system. Use of reservoirs helps the balanced use of the pumping capacity and serves also as a reserve. As more pump is applied in the pumping station, the shift can be more flexible, it can follow the change of the hydraulic load. The use of different performance pumps can ensure the flexibility, as well. Generally, it is better if the pumping station is equipped with some smaller pumps, some mid and high-capacity ones, with more turn on levels. The capacity of pumps can be regulated by frequency converters too. The modern pumping stations are equipped often with frequency converters. The determination of the applied pumps is the question of a complex analysis of hydrological, hydraulic, and energetical issues.

Seepage control in built-in areas

Seepage occurs between the two sides of the defence line; the energy level of water is higher on the flooding side, and the water seeps toward the lower energy level defended side. The groundwater level rises in the defended side because of the seeping from the flooding water body and because of those waters which keeps towards the recipient water body. These result in the wetting and inundation issues of subterrain facilities, as basements, public utilities; the seeping water can cause soil boiling, washing out of fine soil grains, etc. The water can appear in terrain depressions as well.

The appearing water can cause the buoyance on structures if their weight is lower than the power of hydraulic uplift.

The control of seepage can be ensured by:

- the total closure of water transmitting layer – it causes backwatering without groundwater control
- the partial closure of water transmitting layer (vertical lengthening of the seepage line) – reduces the rise of the groundwater level
- widening the foundation of the dyke (horizontal lengthening of the seepage line) – reduces the rise of the groundwater level
- frontal or core insulation – reduces the rise of the groundwater level
- the drain on the protected side (groundwater control) – reduces the rise of the groundwater level

The mentioned technical solution has relevance mainly in case of built structures, but some of them can be used for temporary (operative) flood protection facilities, the seeping line can be lengthened by impermeable structure, first of all nylon foil. As the seepage is pressure dependent, the height of temporary structures is limited by seepage.

A traditional procedure for the control of seeping in the operative flood protection is the counterpressure basin to control the seepage on surface, leakage or soil boiling (concentrated seepage) from the earth, or cracks of pavements or walls, etc. It is a widely used complementary tool for traditional operative flood control, practically for any structures. Traditionally, the counterpressure basin can be made of sandbags or if there is no other way, using any other available material. Building of counterpressure basin is a flexible structure depending on the building technology, it can be built following the terrain' level and the available place; it is very important in urban environment. The most flexible building material is the sandbag, it can be joined to almost any walls, earth structures, despite of its work demand. The well-built sandbag structures are largely impermeable if the bags are placed in a regular way, and the layers of sandbags are compacted. The counterpressure basins must have overflow to control the water level. The overflowing water must be taken into a recipient. In urban environment it can be a sewer.

Public utilities – blocking of secondary flood phenomena

Public utilities in the urban environment are excellent possibilities for water transmission, the directly or indirectly (seepage). As in case of seepage, the place's exposure to the appearance of water depends on the pressure circumstances, or in other words, the relative height position of the surface or the facilities, by the law of communicating vessels. If the defended object and/or its environment is lower than the flooding water's level, inundation can occur.

The water can be conducted directly in water utilities, or in the ducts of non-water utilities or defence ducts for water utilities. The abandoned and forgotten gas, hydrocarbon or heating water pipes do similarly as water or wastewater pipes, if the flood water gets into the pipe.

The operating water and waste water conduits can be simply blocked by valves. The same can be do with gas or other fluid-transporting conduits. In the case of the ducts of any kinds of utilities sealing can be applied. The sealing must be qualified for the possibly occurrent pressure level.

The abandoned, forgotten pipes can cause inundations, taking the water from the flooded area towards the defended sites; this issue can be managed temporarily by blocking the pipe, and after flood event, the conduit must be demolished. The malfunction of pressured public utilities can occur during floods, since the seeping water can cause decrease of load bearing capacity of the earth and uneven vertical movement; the result of this process can be the failure of public utilities. The gas pipes' failure can cause the danger of explosion, the water p'pe's breakdown results in washing out of earth. If it happens at the defence line, in the worst case the flood burst out towards the defended territory.

If a gravitational pipe suffers a failure, the water can get into the tube, washing away the soil through the pipe, and this causes the depression of the surface, collapse of pavements of roads, sidewalks, etc.

The water can provoke flooding somewhere else, in cellars for example. These errors can be prevented observing the related rules of approaching and crossing the defence lines by the public utilities.

Another category of threatening is the potential seeping around the public utilities. During the construction of the public utilities the earth has been disturbed, and changed to graduated material. This results in the increasing of seepage capacity of the earth around the pipes. The cause of this increasing can be: the

- inadequate compactness of the earth disturbed by the construction of public utility;
- grainy bedding layer below or around the pipes;
- seepage at the contour surface of the tubes in the earth.

The problem of seepage at the contour surface can be solved by closing the way of water, using cut-off-plates, or collars to block or lengthen the way of water. In reduction of the seeping, the compactness of the earth and the bedding layers around the pipes has importance. In some cases, the regulation of building ductile material pipe limits the compactness to secure the intactness of the pipe. This issue can be solved using a stronger pipe at least on critical places around, making a mechanical defence defence for the lighter tubes. On these strong pipes, the cut-off plates can be made, and the slot between the two pipes can be closed with some flexible sealing material. The cut-off plate must be wide enough to close the possible seeping in the bedding layer and in the zone around the pipe.

Pressure pipes for gases and liquids

Pressure pipes are equipped with valves which can be used as a closure for flood protection aims. These public utilities generally must work during floods, so the valves should be closable, operable during the floods as well.

Gravitation pipes, hollow pipes for periodical operation

Gravitation pipes are generally rainfall and sanitary sewers. The rainfall sewers have intake generally to the have flooding waterbody.

The sanitary sewers can be or separated or combined.

The flood water can get into the rainfall drainage sewers through the gullies, and by infiltration through manholes and pipe fittings. The free outflow is not possible if in the recipient water body's level is high, so the earlier detailed closure and pumping is necessary. The same is true in the outflows of combined sewers, in this case the treatment plant must receive an greater volume of water. This last situation is true in separated sewers too. The flood water can get into the conduit, but in this case the increased discharge of water can get directly to the treatment plant, or it can cause combined sewer overflow, despite that originally these pipes were designed for the sewage runoff, exclusively.

Operative flood control tools

The operative flood protection covers any flood control intervention which is related to an ongoing flood event.

In urban territories, the flood protection facilities are generally existing, and only some defection must be managed, for example lack of drainage, inadequate height of dykes or flood walls, or some seepage issues. The aims are the ensure of inundation free state of the urban territories, exclusion of life losses, minimization of damages, maintenance of the operability of the town.

The traditional tools of the operative flood protection is the sandbag. However, the sandbag seems to be an archaic tool, its flexibility and favourable characteristics keep it in the focus. Positive, that only the sacks are necessary stored for the flood protection use, the sand can be transported from anywhere, mines, construction sites, depending on the urgency. If there is no available sand, as an ultimate possibility, almost any kinds of earth can be utilised. For the filling, civilians can be mobilised, since it does not demand professional knowledge. The filling can be mechanised to a certain level. Building a sand bag work demands a professional who can command a group of professionals or voluntaries; with a professional direction, any kinds of sand bag works can be constructed. The most important fields of the operative flood protection interventions are:

- heighten the defence lines where it is necessary, with temporary solutions
- counterweight to balance the buoyance of subterrain chambers, manholes, etc.

- control of sewer overflow by weighting the manhole covers
- construction of counterpressure basins
- strengthening the stability of structures, gates

As complementary materials, PVC foils can be used to diminish the wetting of sandbag works.

Further traditional materials are the clay, wood beams, boards, practically anything what can be available in mass, and can be utilised in a relatively simple way. Negative characteristic of traditional tools and materials that after use, a lot of them must be taken into landfills. The use of materials can be counted in hundreds of tons. Regarding sandbags, the reuse of plastic sacks has low possibility, because this material is not UV stable and the Sun ray decompose it within weeks. Originally the sandbags were made of jute; those sandbags were recycled, cleansed, and stored in for a next use; their application seemed to be uneconomic in the past decades. The wood materials must be cut in size; after flood utilisation is limited. But, traditionally, even beyond the sandbag, anything can be used to prevent the inundation, and gives hope to prevent the harms.

An old idea is to diminish the wastes of flood protection materials, the research for well-designed, multiple applicable solutions, which would be developed explicitly for flood protection.

Heighten the defence lines with temporary dykes or barriers

If the water level exceeds the level of the defence line, heightening of the defence facilities is a plausible solution.

It can be done using traditional sandbag wall, or applying modern products to reduce the working hours. The new solutions are generally more expensive, and in the most of the cases, demand professional personnel.

Control of buoyance

There are several underground structures in the urban areas which are sensitive to the hydraulic uplift. The uplift power can be balanced with weighting. These interventions can prevent damages of manholes, under surface chambers, basins, the connected pipes, and in some cases the harm of road pavements.

The weighting together with the other stabilisation forces must exceed the uplift power. The weighting can be made of sandbags, filled water tanks, deposed of earth on the endangered facility, or sometimes vehicles. (Figure 18). It is proposed to overweight the facility approximately 1.5 times, for security considerations.

Figure 18. Weighting of underground railway by vehicles (buses and garbage collecting lorries) in a highest ever flood, 2013 Budapest (Budapest Sewage Works)

Figure 19. Weighting of manhole during the 2013 Budapest flood (Budapest Sewage Works Ltd.)

In the case of the weighting of manholes and chambers under pressure of the flood, the weighting must exceed the direct uplift power awakening on the bottom surface of the manhole cover. This solution works if the weighting is at least 1.2 higher than the uplift power. Near the balance, the gaps around the manhole cover will leak. In this case an alternative of weighting can be the construction of a counterpressure basin (Figure 19). The drainage of the leaking water is to swallowed by the local rainwater sewer.

Figure 20. Counterpressure basin over a manhole, the overflow is not necessary in this case (Budapest Sewage Works Ltd.)

In the case of underground chambers, which are not water sensitive, but their structural secure is not enough against the hydraulic uplift power, another way of the counter-weighting is the flooding of the chamber. The chamber can be filled up from running water, pumped water from the flooding water body, or there can be built in wells on the bottom of the facility to fill up the internal volume to a specific level.

If the chamber or its installations cannot be flooded, the chamber should be weighted. The load can be anything which can increase the resistance force against the uplift force. In case of smaller manholes, chambers, sandbags, filled "big bags", earth or rock depos can be used. Sometimes the load bearing of the chamber's bottom plate is question marked. In this case, the chamber's bottom must be weighted. When the weighting is placed on the slab, and there are holes on the slab, the holes must be covered a load bearing plate or boards, etc., and a 1.5 mm thick nylon foil must be used under the mound of sand or earth. Loading of greater structures can be done by vehicles, as happened in 2013 in Budapest during the flood of the Danube, when the tunnel of the local train was loaded by unused trolleys, buses and even sanitary tracks (Figure 18).

Control of sewer overflow

A sewer overflow can occur if there is high water on the recipient, or an intensive rainfall causes overload, or because of the combination of these two causes. Less frequently, also extreme seepage can cause overload by infiltration or breakdown of sewer. The overflow is the consequence of a high energy, over the level of terrain. Theoretically, intervention can be the weighting and the counterpressure basins, if the pressure level is manageable. Generally, there is no time of intervention in the case of rainfall caused overflow; these phenomenon takes place within a short time, so a reaction cannot be performed. Since the manholes are mostly in the roads, the intervention could be obstacle by the traffic. In the case of the high water level of recipient, the interventions can be made more easily. If the overpressure lifts up the cover of the manhole, the possibility of success of the intervention is low, in this case the counterpressure basin can be a good solution, but the building of it can be a huge struggle because of the elevate water discharge. In this case the discharge of the outflowing water can be so great that the sandbags or other materials can be flushed away. In this case, the most practical is to drive the water towards a manhole of another sewer line, which can temporarily receive the outflowing water, or to greens.

Summarising, a sewer overflow can be managed if the pressure is not to high in the tubes. In this case, the solution can be the loading of covers, manholes or chambers or by making counterpressure basins around the manholes as it was showed earlier (Figure 19, Figure 20).

Using of new solutions of flood control barriers

As it was mentioned before, there are several newly introduced products for flood protection purposes which can be accepted with reservations regarding the security issues. The main aims of this development are:

- the undisturbed use of urban spaces in flood free periods
- the shortening of the building time of temporary flood protection works
- the diminishing of human work demand
- reusable solutions for economical flood protection methods

The most important characteristics of the temporarily built flood protection solutions and their deployment are the followings:

- structures should be mounted before the flood arrives
- if the building of temporary structure is in delay, the defence capacity is absent
- the applied product can be joined to other flood defence structures, they have to be flexibly joined to walls, dams
- resistant to the surface level depression
- minimises seepage between the terrain and the bottom of the structure
- strong and resistant to the punching or abrasion effects (these are often inevitable during the deployment of these structure)
- resistant to waves
- resistance to the water pressure without slipping
- well determined maximum water level

In the urban environment several dangers threaten the temporary flood protection structures. The urban environment is rather various, with earth surfaces, road curbs with 5–15 cm steps, unevenness, poles, rails, walls of buildings or flood protection walls, etc.

The applied product must be linkable to these objects simply and secure way. There must be sure way of fixing any probable leakage or breakdown with some complementary structure, as foils or sandbags.

There are several types of temporary flood protection solutions which can be joined to vertical surfaces with significant difficulties only, for example the water filled cylindric composite plastic-tissue tubes (Figure 21.). These products cannot be formed to angular, so in the angles of the terrain and wall the waterproof joining is impossible. These gaps can already cause a significant water discharge with some 10 cm pressure.

Figure 21. Inflatable barrier during the 2013 Budapest flood (Budapest Sewage Works Ltd.)

Similarly to the join to walls, the unevenness of terrain can cause flows, despite of the significant weight of the cylinder. Its curvature cannot mime the surface, the gaps let the water flow through below the cylinder causing potentially washing out. The materials of these products are quite strong, but some of them, despite of the really high strength of the composite plastic tissue cannot be resistant to abrasion. When in the construction phase the inflated cylinders are moved to their position, abrasion can occur if the tube touches the terrain. Some of these products have significant size, 10 m or more, so the moving of these elements demands a coordinated work of 6–8 persons. The elements can be built only in a certain direction, so the speed of construction is limited. The filling of the cylinders can be supplied from the flood water, according to the brochures. The flood water is not clear, so the internal surface of the tubes is going to be polluted. After use, the emptying of the cylinders can be solved one by one, since the tubes cannot be disjunct in filled state. The emptying of a 10 m long element takes several 10 minutes, so it can take more time than the construction did. Then remains the problem of cleansing, the internal parts are unreachable, the drying takes very long time. Another issue is the loadbearing which is the function of the inclination. The filled cylinder is prone to crawl downwards direction, and the several tons mass cannot be stopped. If the water pressure pushes the tube, the motion is unstoppable. There is no exact calculation about the real loadbearing, nor experimental verification. However, the material is strong, holes can be formed unnoticeably, the loss of water can be noticed only after filling up, when the change of the tube takes a lot of time. These issues influence the judgement of secure.

Similar questions can be raised concerning the use of flood control barriers with steel structures, and several other products. Without responding these issues, the utilisation of this kind of products can induce problems. A strong criticism is important to avoid a potential failure later, in a real flood protection situation.

The Figure 22 shows a flood barrier which kept 1–1.3 m water with success in 2013 Danube flood.

Figure 22. Steel structure based flood barrier, Budapest, 2013 (Budapest Sewage Works Ltd.)

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