Strategy or disaster: New-style river regulation as an issue of national security[1]

Introduction

About one-fourth of the territory of Hungary is floodplain area, protected by 4,220 km of flood-control dykes. The streams are divided between the systems of two major rivers, the Tisza and the Danube. In the areas endangered by floods 2.5 million people live on almost 700 settlements. This geomorphological surface accommodates almost 32% of railways, 15% of public roads and more than 2,000 industrial plants. Such structures are located encircled by 19,000 to 20,000 km^2 of valuable agricultural land. The large-scale flood regulation works following the formation of the Tisza Valley Flood Regulation Association in 1846, primarily the construction of dykes along the Danube, the Tisza and their major tributaries, changes of the alignment of main channels, the creation of side-branches and main defence lines confining floodways, the establishment of artificial channel sections, the cut-off of bends, the drainage of swamps, the improvement of navigation conditions, the prevention of ice-jam and ice-free floods and investments observing water management and land utilization aspects were the most comprehensive activity of nature transformation in Europe of that time and also the largest-scale regional development programme in Hungary to date.

After 150 years it became clear that the concept was not correct in all aspects due to political and economic decision making, for instance, setting navigation goals allowing too narrow active floodplains, draining swamps on the lower floodplain levels, prioritizing the interests of large-scale agricultural cultivation, deficient design and implementation of main canals (Ihrig, D. 1952). We are aware that since then the stability of embankments has been reduced, the transport capacity of large rivers has increased after regulation, current velocities have increased, low-water beds have incised deeply and deeper channels have led to the sinking of the groundwater table, which – according to Pálfai, I. (2004) – increased susceptibility to drought. We also know that the narrowing of the low floodplain level within dykes results in rapid sedimentation on the active floodplain, the surface of which rises and, thus, the levels and durations of floods of equal height are increased.

The Trianon Peace Treaty dissected the unified flood-control system of historical Hungary. As a consequence, Hungary became defenceless as far as water management is concerned and exposed to floods. River regimes in the catchments encircled by the Eastern Alps and the Carpathians could not be influenced.

Before 1976 the primary measure of flood security was the difference between the highest flood level observed to date and the height of embankment crown. Since 1976 this value is only registered for some river sections. The desirable difference was raised from 70 cm in 1852 to 100–150 cm in 1934, when the dimensions of the minimum dyke cross-sections were also specified. The average difference for the Tisza River was 100–120 m in 1956 and its minimum was above 70 cm along the whole length of the river. Today the average is below 40 cm and over more than a hundred kilometres long section it is below 20 cm. As a consequence, during the 2000 flood a temporary dyke had to be built along a 155-km-long section of the Middle Tisza and the existing dykes had to be raised (Schweitzer, F., Nagy, I. 2011).

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Since 1960 the afforestation of active floodplains began, summer dykes and resorts appeared, arable and grazing lands were abandoned and invasive plants (like false indigo, *Amorpha fruticosa*) started to spread. All these contributed to the rapid rise of flood levels and increased floodplain sedimentation.

Discussion

The water management investments in dyke construction have a lasting impact, for decades or even centuries. Replacements are slow and costly to accomplish. For instance, the active floodplain of the Körös Rivers was designed to have only 50–70 m width in the late 19th century. Beyond the Hungarian-Romanian border, however, floodplain width is 150–200 m. Therefore, water is funnelled into the narrow sections, flood waves pile up and result in dam breaching, boil activity and excess water inundations. To mitigate this hazard the active floodplain in Hungary should be broadened through the backward placement of flood-control dykes (Schweitzer, F. 2001).

Engineering interventions are not able to fully eliminate problems. Regional development and landscape rehabilitation are outstanding tasks. In order to prevent disasters political decisions are indispensable. It is to be noted that in dry periods the awareness of flood risk is greatly reduced in the general public and among most of the political leaders. However, when floods occur again, like in November 1998, when 17 dry years were followed by flood and led to catastrophic situation on the Upper Tisza, opinions and attitudes have to be rethought, even by those who refute the existence of flood hazard.

On the catchments of rivers in Hungary – with special regard to natural and economic processes in the active floodplains – flood levels can rise significantly. The reduction of flood conductivity of the floodway amounted to 3 cm per year for the period 1970–2010 (Schweitzer, F., Nagy, I. 2011).

In the drainage basin of the Tisza River, e.g. on the upper section in the Carpathian foreland, there were 19 destructive floods after 1947 (Vágás, I. 1982, 1984). Researchers see the cause of this in unmerciful deforestation, mining activities and, as a consequence, common landslides and soil erosion inducing enhanced sediment transport. Although the significance of deforestation is debated by some, I. Szikura (personal communication, 2001), a professor of botanic at the Uzhgorod National University emphasizes that the forest foliage intercepts up to half of rainfall, reduces snowmelt to half and increases the amount of infiltration and storage of water in the soil. The fact is also important to note that in the North-Eastern Carpathians the upper timber line has moved 200–300 m lower.

The sediment transport capacity of rivers in the Carpathian Basin has ever been large. Even the settlement on the isolated higher floodplain levels rising above the low floodplain level were occasionally inundated by floods because on the low levels around them silts accumulated. Along the present-day Tisza River, the divide surface of NE to SW alignment, built up of loess and loess-like deposits, was dissected by high flood discharges, e.g. at the breach of the Mirhó Stream. These locations could have been sites of channel changes of the Tisza during floods. Between them the paleochannels of the Tisza can be detected *(Figure 1)* showing huge meanders filled continuously with excess water *(Figure 2)*.

Very rapid urbanization in the drainage basin further enhanced the natural rate of sediment transport over the 150 years of flood defence and sedimentation accelerated on certain sections, manifested in the accumulation of point-bars and natural levees. The consequence was that the heights of the dykes had to be raised time after time, since 1850 on 5–6 occasions (*Figures 3, 4*).

If nothing changes, they have to be raised further (Schweitzer, F. 2001). In the active floodplain of the Tisza River the accumulation of sediment has reached 200–240 cm south of Szolnok and 400 cm on the Vajdaság (Vojvodina) section in Serbia, while along the Körös rivers accumulation amounted

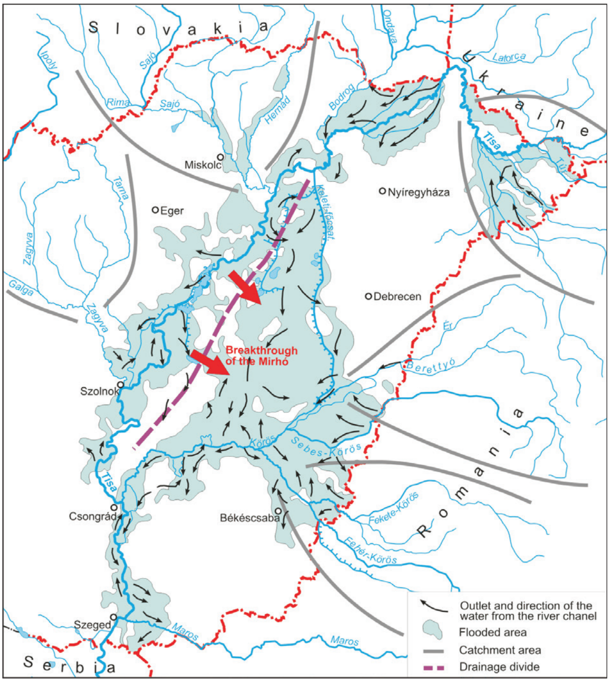
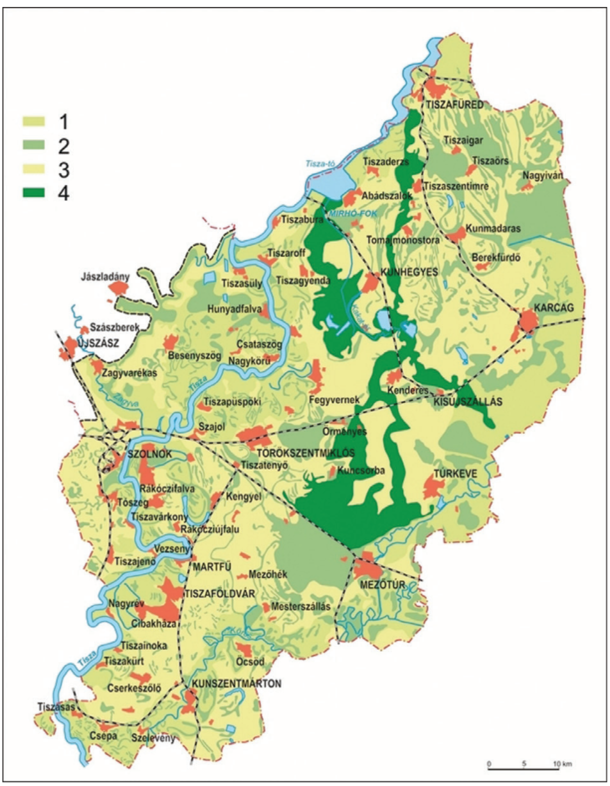


Fig. 1. Waterlogged areas in the Tisza valley prior to water regulation (ed. by SCHWEITZER, F. 2000)



to 140–160 cm. The rapid growth in the rate of sedimentation in the active floodplain is indicated by the distribution of ^{137}Cs in the cross-section at Szolnok (BRAUN, M. *et al.* 2001) *(Photo 1).* Since the Chernobil nuclear accident (1986) sedimentation estimated from the concentration of ^{137}Cs activity is 30–35 cm until 2000. In author's opinion this rapid sedimentation affects the water levels of lakes in Hungary, including Lake Balaton.

In the active floodplains of rivers huge amounts of sediment arriving from the catchments are deposited. Evidenced by the history of dykes along the Tisza (raised on 6–7 occasions), the further heightening of flood-control embankments is no long-term solution (SCHWEITZER, F. 2009).

The floodways are less and less suitable to conduct floods of both the Danube and the Tisza. In 2000, when the largest ever flood passed down on the Tisza, the flood discharge was only slightly higher than in 1970. Maximum flood level, however, was at 1,041 cm at Szolnok, 1.5 m higher than before. The only explanation lies in the deterioration of flood conductivity caused by sedimentation in the active floodplain *(Table 1).*

Fig. 2. Relationship between floods and inundation hazard on the engineering geomorphological map of the Mirhó-fok. (compiled by SCHWEITZER, F., BALOGH, J. 2001). – 1 = low floodplain; 2 = areas with inundation hazard; 3 = high floodplain; 4 = areas suitable for water retention

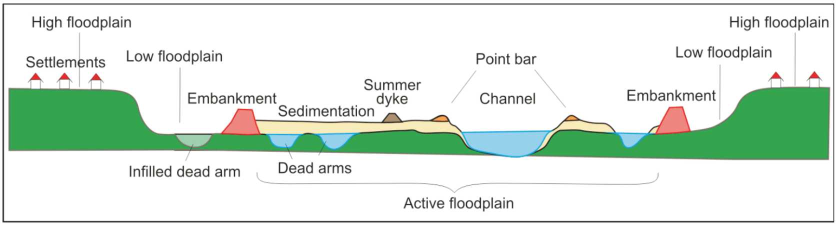


Fig. 3. Rising of the flood control embankments since river regulation (after SCHWEITZER, F. 2001)

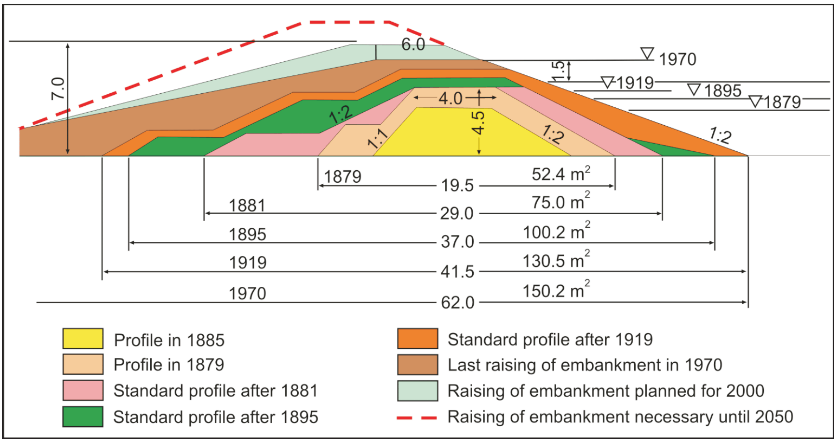


Fig. 4. Rise of the embankments (compiled by SCHWEITZER, F. after VÁGÁS, I. 1982)

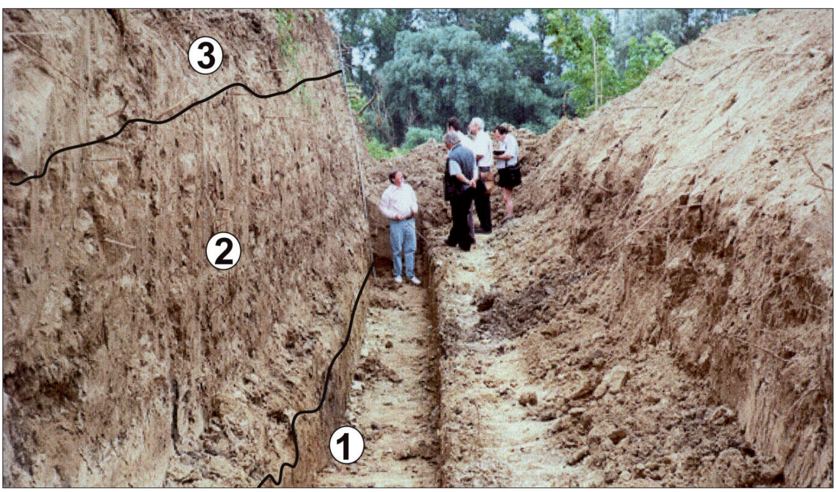


Photo 1. Section South from Szolnok with intense floodplain sedimentation. – 1 = alluvial meadow soil formed prior to flood control; 2 = 200–230 cm thick siltation; 3 = 30–40 cm thick sediments deposited between 1986 and 2000. (Photo by SCHWEITZER, F. 2001)

Table 1. Maximum flood levels at river gauges of the Middle Tisza region in 1999 and 2000

Gauge	1999 maximum in cm	1999 maximum related to design flood level, cm	2000 maximum, cm	1999 maximum related to design flood level, cm	Growth of maximum flood levels compared to pre-1999 period, cm
Tiszafüred	835	+21	881	+67	93
Kisköre	978	+47	1,030	+99	122
Tiszaroff	1,033	+39	1,088	+94	130
Tiszabő	1,023	+19	1,080	+76	131
Szolnok	974	+13	1,041	+80	132
Martfű	926	+3	1,003	+80	115
Tiszaug	844	-36	932	+52	89
Csongrád	891	-80	994	+23	59

Source: Nagy, I., KÖTIVIZIG, 2001.

Unfortunately, this process has been neglected in flood hazard research. Disregarding sedimentation, dyke heights had to be raised in every 20–25 years over the last 150 years (Schweitzer, F. 2000; Nagy, I. *et al.* 2001). If this deterioration continues, the high flood waves of the last decades will return within 15–20 years. This can only be prevented by governmental interference.

Sedimentation in active floodplains is considerable and will lead higher and higher flood levels in the future, as it can be seen on the example of the Tisza, Danube or Körös rivers. A new flood-control concept is also necessary for the Danube which would employ new approaches to flood-level reduction (e.g. floodway reconstruction, water diversion, storage and others) and the raising of the design height of dykes only where the previous techniques remained unsuccessful. In many places of the floodways of large rivers it is visible that the zones where floods are conveyed unhindered are significantly reduced through groynes, higher summer dykes (levees), forestation or housing development *(Figure 5).*

Dense vegetation in the floodway and next to the channel promotes the settling out of sediment load. Therefore, if this geomorphic process is neglected, higher flood levels are to be expected in the future. Within a reasonable time there is no real chance for a new flood channel to form and the opportunity for raising dykes and building reservoirs in the low floodplain level is restricted or even excluded by both engineering and financial considerations. In addition to these three options, a fourth one has to be mentioned: the preparation of society for a new-style river regulation, establishment of new channels.

Fig. 5. Shrinkage of active floodplain of Tisza in Serbia due to the construction of levees (eds: Nagy, I., Schweitzer, F. 2011 by using Google Earth images)

Since the beginning of river regulation efforts 150 years elapsed. Since then the active floodplains have filled up, narrowed and higher and higher floods of increasing frequency and duration are predicted, primarily as a consequence of sedimentation in active floodplains and developments in the embayments of low floodplain levels, along the Danube at Pilismarót, Pomáz, Békásmegyer, Káposztásmegyer (Budapest) and Adony and along the Tisza in the environs of Szeged and Hódmezővásárhely. The plans and decisions of new river regulation have to be made soon. The Department of Geomorphology, Geographical Research Institute, Hungarian Academy of Sciences , and the author of the present paper have prepared, based on geomorphological and hydrogeographical investigations such plans for flood control along the Danube at Budapest, Paks and Komárom, for the Tisza at Szeged or for Lake Balaton.

Intensive urbanization in the Balaton catchment, the refilling of the karst reservoir in the wake of closing bauxite mines since the 1990s and the re-emergence of karst springs will increase the amount of water stored in Lake Balaton.

A turning point in the development of the region was the construction of the southern railway. Its planners designed the track at 107.7 m elevation, higher than maximum lake water level. In the winter of 1860 raised water level and ice accumulation destroyed the railway track.

As a reaction, the Balaton shore was enforced, some sections – particularly on the southern shore – were filled up, reclaimed areas protected by stone revetments were allotted for development. Datings by ^{137}Cs show that the lake bottom was affected by sedimentation of almost 20 cm since the beginning of nuclear experiments (1953) and another almost 10 cm since the Chernobil event (1986). Therefore, in the future the Siófok Sluice, already existing in Roman times, and the Sió canal is to be supplemented with a new outlet, gravitationally conducting water into the Mura River during floods (Schweitzer, F. 2014).

Conclusions

The study of flood levels shows that the rise has considerably accelerated and the height of flood waves surpassed the crown of the embankment along more than 200 km length of the Tisza (Nagy, I. *et al.* 2001). As a result of the deteriorated conductivity of flood channels, for instance, the growth of flood waves on the Tisza between 1970 and 2013 reached 2–3 cm per year. This can be observed on the Danube, where average increase amounted to 1.40 cm per year between Vác and Budapest over the same period, on the Körös, where it was 1.60 cm per year at Békésszentandrás since 1890 and in case of the Ipoly. In practice it means that if the 2000 Tisza flood were repeated today, the flood channel would not be able to convey that flood wave and only the emergency reservoirs could give some hope to avoid disaster. The marked rise of flood levels could be interpreted as warning for the Danube too as 20–25 cm sedimentation is expected in the active Danube floodplain in the Danube Bend, north of Budapest, in the next 10 years *(Figure 6).*

The key to flood control in Budapest, a city of 1.8 million, inhabited from Roman times, is river regulation. The main channel of the Danube crosses the city in 31 km length. Together with the banks of tributaries the length of flood-control dykes amounts to 83.6 km. As attested by written documents available since 1112, flood hazard has ever belonged to city life. The greatest disaster was the ice-jam flood of 1838 *(Figure 7).*

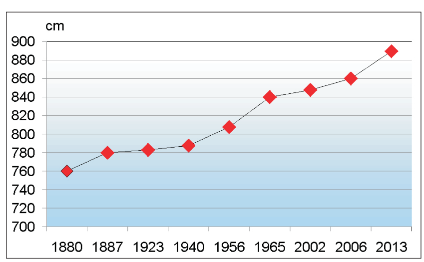


Fig. 6. Rising of peaks of largest ice-free flood levels on the Danube section at Budapest between 1880 and 2013 (completed after Dégen, I.)

Fig. 7. Flood damage map of 1838 superimposed on the current area of Budapest. Google Earth images (ed. by Takács, K. in 2009 after Károlyi, Z. 1960)

After the flood plans for not only the Danube section of Pest-Buda, but for all major rivers in Hungary were prepared and submitted to the government. Naturally, lack of financing in times of the revolution and war of independence prevented the implementation of plans. Instead the filling of low-lying areas, Danube branches between one-time islands, abandoned channels, backswamps, began mostly using industrial waste and household garbage.

Between 1871 and 1875 the Soroksár Danube branch was closed by Gubacs dam and the channel section with numerous bars downstream Pest was narrowed down, resulting in the sedimentation of the Soroksár branch which continues to our days. In the spring of 1876 two flood waves similar to the 1838 level occurred on the Danube again endangering Budapest. This was commonly explained by the closure of the Soroksár Danube and its eliminated water conduction. Over the past 60–70 years ice-free flood levels have remarkably risen in Budapest: 1956: 721 cm, 1975: 776 cm, 1991: 781 cm, 2002: 848 cm, 2006: 860 cm and 2013: 890 cm.

Modifications of the floodway signify an impending disaster. In order to avert it, author proposes a solution affecting the left-bank zone between Vác and Göd, where topographic conditions are favourable for flood hazard alleviation and urban infrastructure is not an obstacle. Another option is to protect the 800,000 inhabitants of the historical city applying mobile dykes along the main defence line and the tributaries.

To reduce flood hazard, the active floodplains of rivers have to be widened on the Hungarian, Slovakian, Subcarpathian and Vojvodina sections, water storage on the low floodplain level, the creation of new flood channels and setback of flood-control dykes and locally the broadening of active floodplains to the margins of higher levels as natural levees (see *Figure 4*).

The areas suitable for flood and excess water storage have to be utilized for that purpose in the regional plans, excluded from development, land purchase have to be prohibited and land use regulated in the interest of flood-control strategy. Disinterest in flood protection and national security is manifested in public thinking which allowed the alignment of the M6 motorway cutting through the Adony embayment, which could have been capable to store considerable amounts of floodwater and reserve drinking water with gravels of Danube origin in great thickness between Ercsi and Kulcs (Nagy, I. *et al.* 2010). Instead of momentary solutions politics have to decide for change. If this does not happen, floods would require much suffering and human toll in the country – not to speak of the enormous expenses of reconstruction. The estimated damage associated with the 2006 Danube and Tisza floods surpassed 135 billion HUF. In the case of the Tisza flood in 2000 eight million sand bags were built-in in the dykes and flood defence involved additional high costs. The 2013 Danube flood also caused huge damage.

In Hungary the tasks to be undertaken now are similar to those in the 1830s and 1940s. Long-term strategic decisions have to be made in order the ensure security for the population living in river valleys and floodplains and for agriculture and industrial structures.

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