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GEOGRAPHICAL AND GIS ANALYSIS OF THE GREAT FLOOD OF 1838 IN PEST-BUDA

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ABSTRACT:
This paper analyses the Great Flood of 1838 with the help of geographic information system (GIS) tools. The flood reached its peak on 15th March at the Pest-Buda section. "Great floods" were able to develop due to different reasons. The icy flood of 1838 was caused by the sudden onset of high water levels in spring, after a sustained cold period and ice formation. That year, melting began earlier at the upper section of the river than in the lower parts of the Danube Valley, namely in the Danube Bend area. Damage assessment began immediately after the recession of the flood. During the analysis of the flood events, we aimed to find out which settlements were most affected by the destruction of the flood, and why. Furthermore, we examined the data from the relevant mapping reconstructions to determine whether there was a connection between water depths and the location of the Paleo-Danube beds. We also described which areas remained dry during the flood, offering safe places to the people. We have compared all these with the information of historical descriptions, and related them to the geographical environment based on military and other maps.

Key-words: *Flood, Historical geography, Settlement development, Pest-Buda, GIS.*

1. INTRODUCTION

Floods are a natural phenomenon which is known from the beginning of human civilization. Storms, floods are the most frequent natural disasters in Europe in past and in today too, (Klemešová, Kolář & Andráško, 2014)

The flood of March, 1838 was one of the greatest natural disasters in the history of Hungary. Dozens of people, several municipalities and thousands of houses fell victim to the icy deluge. Buda, Pest and Óbuda – the ancestors of the present capital – suffered the greatest losses and casualties. Csepel and Albertfalva, two settlements to the south of these towns, were also greatly destroyed by the flood. The geomorphological features and settlement patterns of the region played an important role in the extent of the destruction. Almost every settlement affected by the flood was built within the floodplain area in the second half of the 1700's, for example Óbuda, Csepel or Tétény. Before the river regulations, the sandbars Kopaszi Bar and Nyúlfutási Bar were located at today's Lágymányos, with a width of approximately 1 km. These two reefs and Csepel Island blocked the way of the ice, and caused icy floods in the area. Those settlements, however, that were built on hillsides or on one of the Pleistocene Danube terraces (II/a or II/b), remained mostly intact.

An investigation of the history and physical geography of the settlements with the help of GIS-analysis is important because of the following:

- this is the one of the interesting field of geography (physical geography, settlement geography, historical geography, etc.);

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- it shows the pattern of the space structure (Bujdosó, Dávid & Uakhitova, 2013)

Having said that, publications on the Great Flood of Pest-Buda in 1838 usually do not discuss or analyze the complex chronological and spatial order of events of the flood. However, Budapest, the capital city of Hungary with almost 2 million inhabitants still lies on the two sides of the River Danube. Owing to global warming, floods tend to be more rapid and higher than before. Although embankments and dikes have been built since 1838, the basic geographical features of the area have remained the same. Therefore, a thorough analysis of the relatively well-documented Great Flood can shed new light on present day flood control plans. This study focuses on the complex examination and the modeling of the flood events using GIS tools. The analysis is based on contemporary and later maps, and on statistical and historical data.

2. METHODS AND DATA

Instead of classic GIS software (e.g. ARCInfo, Idrisi, MapInfo, Surfer, Quantum GIS etc.) AutoCAD, a program usually used as a drawing tool, was applied during the analyses. The main reason for choosing this software was that several maps had to be drawn based on contemporary maps in order to re-create the environment. The base maps, as well as different spatial and temporal data, had to be layered on each other with the help of reference points. Then, data contents were assigned to the different map objects. As soon as the necessary amount of data was available in the databases of the maps, queries could be submitted.

Whilst analyzing the events of the flood, a number of maps were used, e.g. the maps of the 1st and 2nd Military Mapping Surveys and other (physical, topographic and thematic) maps showing the geographical environment, the geomorphological circumstances of the time and the events of the flood. Statistical data were obtained from literature on the flood events. Before starting the spatial analysis, all base maps had to be transferred into the same system. For this, we had to find common points – reference points – that still exist today, e.g.: churches, important public buildings, junctions etc. The coordinates of these points were allocated by Google Earth 5.0. As the Google application works with WGS-84 coordinate system, the results had to be converted to EOV coordinates (Zaletnyik, 2005). The resulting EOV coordinates were then transformed by the GIS based program used during the research.

After creating the georeferred database, the thematic maps and figures were projected to military maps, also with the help of common reference points. However, the aforementioned georeference method may result in variances of some 10 meters in case of certain locations. One reason for that is that it was not possible to find correct reference points with exact coordinates, because the maps of the 1st and the 2nd Military Mapping Surveys were not detailed enough, and worked with different scaling systems. For example, the military maps mark churches and junctions with only small dots, while in Google Maps, these locations – and their coordinates – can be measured even by centimeters, if required.

The different projection systems of the maps also caused inaccuracies. The 1st Military Mapping Survey used no projections or base map layers and contained no elevation data. The 2nd Military Mapping Survey also had no base map layer or elevation base points, but it had a projection – the Cassini Projection (Kovács, 2002). Google Earth operates with the Universal Transverse Mercator (UTM) projection system. With the above problems taken into account, the georeferred maps contain inaccuracies up to 20-50 meters. However, these differences still allow the reliable cartographical reconstruction of the flood events.

Different thematic maps were layered on the military maps. To illustrate the former beds of the Danube, The paleohydrographic map of Budapest by László Góczán was used (Lászlóffy & Csermák, 1958). This map was layered on the base map of the 1st Military Mapping Survey. The water depth map was based on the 1838 base map by Lászlóffy, (1938). This layer was placed on the base map of the 2nd Military Mapping Survey, together with the map of the Paleo-Danube beds. The map about the largest extent of the flood was created using different thematic maps that were layered on the base map of the 2nd Military Mapping Survey. The most important among them was The water covering of the 1838 flood in the area of today's capital, by Woldemár Lászlóffy (Lászlóffy & Csermák, 1958). The data of the Pest and Buda flood were refined on the basis of the map entitled The destruction of the 1838 March flood in the capital (Lászlóffy & Csermák, 1958). The original map was the supplement of a charity publication published by the 5th Artillery Regiment stationed in Pest at that time. The parameters of the flood in the area south of Pest were compiled on the basis of a map entitled The river Danube before regulation and areas affected by the 1838 flood, published as an insert of (Bolla, 1976).

For the compilation of the map database, statistical data on the flood were gained from different resources. Most of the statistical data was collected from (Faragó, 1988), providing detailed information about the destruction of buildings in different quarters and settlements. Further data were obtained from (Lászlóffy, 1938), including information on water heights (depths) and data about the damage on buildings in different quarters and settlements. Another important source of information was the historical description (Nagy, 1975).

3. ANALYSIS

3.1 Pest-Buda: the 1st Military Mapping Survey

The 1st Military Mapping Survey, exploring the territory of Hungary, was carried out between 1782 and 1786. The map series covered the whole of Hungary at a scale of 1:28 800. Pest-Buda and the surrounding area is illustrated on pages 14/20 and 14/21, and these maps were finalized in 1783 (Fabók, 2005). At that time, the Danube and its tributaries were absolutely unregulated. In these maps, the islands of the river are intact; several amongst them would disappear or "transform" into peninsulas in the future centuries, due to landscaping activities. The Kopaszi Bar and the nearby Nyúlfutási Bar at the widening of the river (illustrated without its name in the original map) were to act as important mechanical obstacles in the way of the icy flood in 1838.

Fig. 1 shows that the abandoned beds of the Danube (Paleo-Danube) are situated in the area of the present floodplain. These beds were not filled then, and therefore acted as temporary watercourses or catchment areas, or served as beds for surface watercourses, e.g. the Rákos Stream. The map shows that most of the settlements – Pest, Óbuda, Csepel – were built directly on the riverbank, within the low floodplain areas. At that time only Buda, Pest and some parts of Óbuda had urban characteristics with well-built multiple storey buildings (Lászlóffy, 1938)].

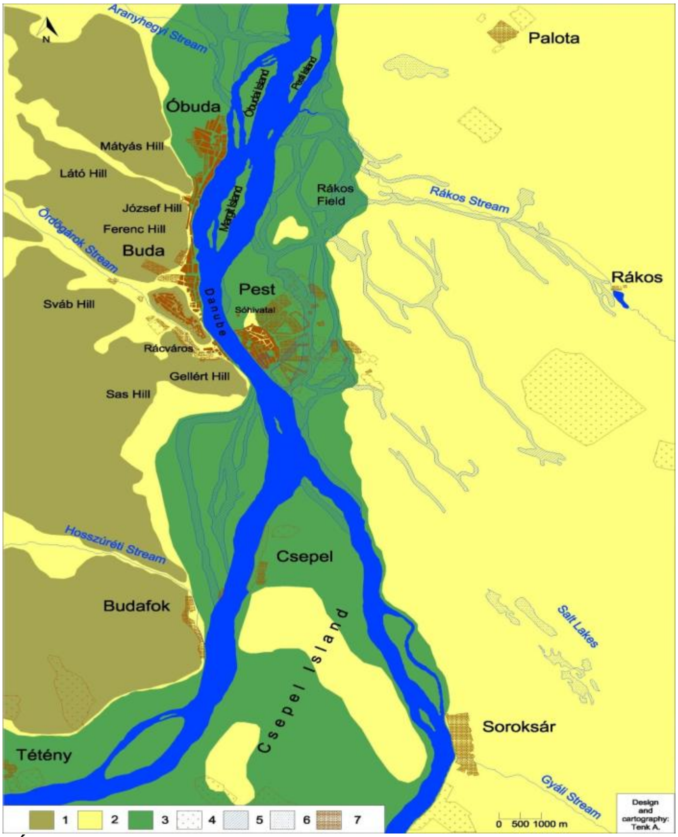

Fig.1 Pest, Buda, Óbuda and the surrounding area with the beds of the Paleo-Danube at the time of the 1st Military Mapping Survey (Legend: 1 = hilly area; 2 = plain; 3 = floodplain; 4 = garden, vineyard; 5 = former river bed; 6 = marsh, swamp; 7 = settlement)

The semi-circular shape of Pest's eastern side follows the former medieval city wall. The Military Mapping Survey also shows some parts of this wall. Today's Lesser Ring Road [Kiskörút] was built along this line.

3.2. Floods in Pest and Buda in the 18th-19th century

In Hungary, icy floods are the most dangerous of all floods possible in a four-season climate. It might occur when a short period of thawing or the general warming of spring breaks up the ice cover of the river and debacle begins on the Danube. Sometimes the drifting ice piles up – either because of a narrower section in the river bed, or due to a colder period of weather. In case of such events, the increased amount of water cannot run off between the riverbanks, and large areas may be flooded. This type of flooding has occurred several times on the Danube (Lászlóffy & Csermák, 1958) **(Fig. 2)**.

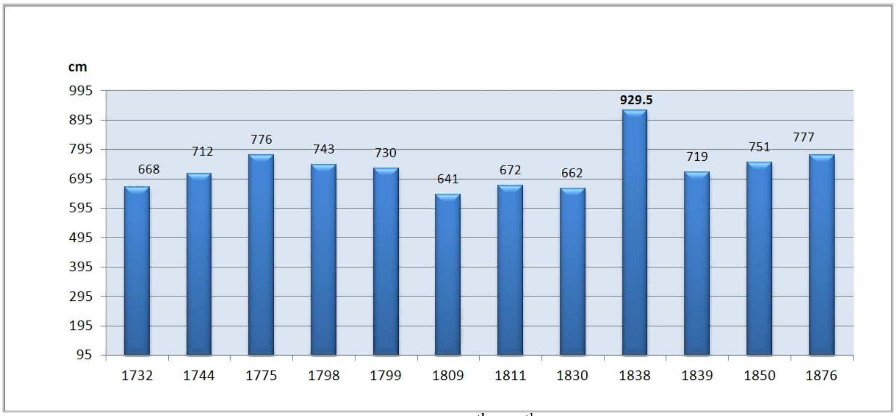

Fig. 2 The peaks of major floods in Pest-Buda of 18th–19th centuries Source: own edition based on data by Lászlóffy W. (1938).

The story of the 1838 flood can be reconstructed as follows. The Kopaszi Bar used to lie in the section between today's two bridges: the Szabadság Bridge and the Southern Railway Bridge [Déli összekötő vasúti híd]. Here the river widened to almost 1 km, and the reef ran from the right bank to the centre of the riverbed. Just south of the Kopaszi Bar, the Danube branched at the northern tip of the more than 50 km long island, the Csepel Island. The left Danube branch, the Soroksári Branch has always been narrower and shallower than the main riverbranch. Therefore, the drifting ice could block the narrow watercourse. Further ice floes coming from the north piled up on the already present ice barrier in the Soroksári Branch at the tip of the large island, creating a 4-5 m high ice wall.

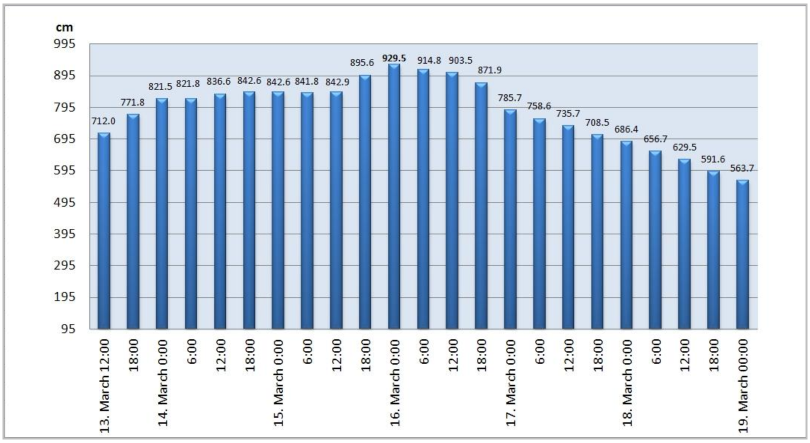

Fig. 3 The changes of the water level in Buda in March 1838 Source: own edition based on data by Faragó T. (1938).

Meanwhile, the ice at the Kopaszi Bar blocked most of the riverbed. Due to a persistent freezing period, a 2-3 meter thick ice sheet was created, and the ice reached the bottom of the riverbed at several points. The accumulated ice put the capital in peril. The ice pile at the top of Csepel Island filled the left side of the riverbed on a 1 km section, in the direction of Pest-Buda, and the quantity of the flowing water was further reduced by the block around the Kopaszi Bar. The weather stayed very cold during February, with temperatures below -18 ºC. When finally milder days came at the end of February and at the beginning of March, the water level suddenly rose to 670 cm by 9th March (Lászlóffy, 1938).

The main reason of the tragedy was that the ice cover of the river had sunk approximately 1 meter due to lowering water levels between 19th and 25th February, and the ice compacted. Spring warming began earlier at the upper section of the river than in the middle parts, and as a result, the ice carried by the thawing water was caught up on the ice blocks in the middle section (around Pest-Buda and Csepel Island), and jammed the river even further. This happened at a crucial time when the water level was expected to rise constantly because of the warming in the upper areas. The Danube first burst its banks on 6th March. On 13th March 1838, the water level rose to 712 cm. On 15th March 1838 – exactly ten years before the 1848 March revolution – the flood reached its peak at 929,5 cm in the capital (Lászlóffy, 1938) **(Fig. 3)**.

Before midnight that day, the ice pack at Soroksár started to move and just like the jammed ice mass in the other branch of the river at Budafok a few hours later. Finally, the waters of the Danube found their way to Danubian Plain [Duna menti síkság] on the left of the river and raced through the huge Csepel Island, causing significant destruction in the settlements of the area (Lászlóffy, 1938).

The water first reached inhabited areas on 6th March, when the districts Víziváros and a part of Rácváros (Tabán) were flooded on the right bank in the city. On 13th March, even Óbuda got under water. In Buda, the water broke into the houses in Fő Street through the ground floor windows. On the Pest side, the dikes withstood the flood until 9 a.m. that day, when the flood broke through in upper downtown, at the Vigadó. Around midnight, the Váci Dike – built in 1775 between the present Nyugati Square and Lehel Square – broke down, and the flood took over the northern part of Terézváros (6th district at present). On 14th March, Soroksári Dike – built in 1775 between present Boráros Square and Haller Street – also collapsed, and the icy water flooded the district Ferencváros (Kiss & Winkler, 1974) **(Fig. 4)**. Finally, by 6 a.m., the water arriving from three directions flooded the majority of the Inner City [Belváros] and Lipótváros, and by that time, the surrounding districts, Ferencváros and Józsefváros were also under water.

The flood reached its peak on 15th March at 929,5 cm. At that time, almost the whole area of the inner city was flooded. The width of the flooded area between Pest and Buda was 2800-3200 m, while between Tétény and Soroksár, a 10,600 m wide area was under the icy water for two days (Lászlóffy, 1938). The quick spreading of the flood was also fastened by the former riverbeds of the Paleo-Danube: the water easily found its way in these waterways, and the city of Pest got flooded at a high speed. This could happen because the paleo-beds are located at the lowest level, and these were directly connected to the active branch of the Danube. The fortification of these riverbed remnants in the 18th century had been based on the experiences during pervious floods.

The map used for the analysis of the flood is a black and white manuscript from 1836, operating with the data of the 2nd Military Mapping Survey (1860–61), at a scale of 1:57 600, edited by Matkowitz. A. L. (Fabók, 2005) The elaboration of field objects, water courses and settlements are more exact than in the case of former maps **(Fig. 8)**. The map also indicates new settlements like Palota or Rákos. Smaller villages like Csepel and Tétény were in the process of development at the time of the mapping. The growth of settlements can be tracked down by the comparison of the maps produced by the 1st and the 2nd Military Mapping Surveys. Pest and Buda had gone through significant changes; especially the size of Pest had grown considerably. The development and expansion of Pest mostly took place directly along the riverbank, still within the floodplain area. It is also important that there had been constructions carried out in the former riverbeds, without actually filling the old beds first.

Fig. 4 Flood in Pest on 13th–14th March (Legend: 1 = hilly area; 2 = plain; 3 = floodplain; 4 = garden, vineyard; 5 = forest, meadow; 6 = former river bed; 7 = flood barrier; 8 = direction of the flood; 9 = built in area).

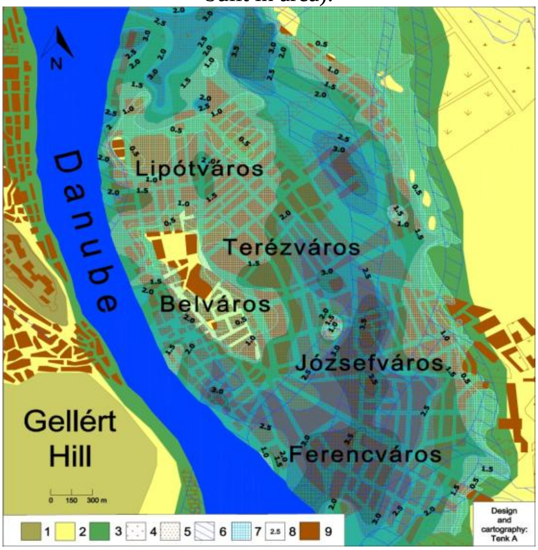

Fig. 5 Water depths in flooded areas in Pest with Paleo-Danube river beds (Legend: 1 = hilly area; 2 = plain; 3 = floodplain; 4 = garden, vineyard; 5 = forest, meadow; 6 = former river bed; 7 = flooded area; 8 = water depth, m; 9 = built in area)

In Pest, about 1,300 acres (748 ha) of the populated area was flooded, with only about 37 acres (21 ha) remaining dry. The largest flood-free area was in the city centre, today bounded by József Attila Street, Bajcsy-Zsilinszky Street, Deák Square, Gerlóczy Street, Városház Street, Szervita Square, Bécsi Street, Harmincad Street and József nádor Square. There were some dry areas at Ferenciek Square, at Nádor Street between Kossuth Square and Zoltán Street, and at Podmaniczky Street (all names used here are current street/square names) (Nagy, 1975). Other dry areas were at Ferdinánd Flyover and at Benczúr Street between the Bajza Street and Felső erdősor Street. On the Pest side, the average water level in the city centre was 200 cm, in Józsefváros 216 cm, in Terézváros 208 cm and in Lipótváros 150 cm. The highest water level was measured at the junction of József Boulevard and Baross Street with a peak of 380 cm. The water also reached more than 350 cm height around Nyugati Square, at the junction of József Boulevard – Üllői Road and around Rákóczi Square (Lászlóffy & Csermák, 1958) **(Fig. 5)**.

The map below **(Fig. 6)** clearly shows that almost every town and village built in the lower areas of the flood plain was affected by the flood. Almost the whole town of Óbuda and Pest fell victim to the floods. Csepel, Albertfalva and Tétény were among the smaller villages seriously damaged. In Budafok, the icy flood only took over in the flood plain areas. Soroksár was built on the flood free Neopleistocene II.a) and II. b) terrace (Lászlóffy & Csermák, 1958), out of reach for even the highest water levels. Due to its favorable location, the town was spared. **Fig. 6** illustrates the flooded areas and settlements around Pest and Buda.

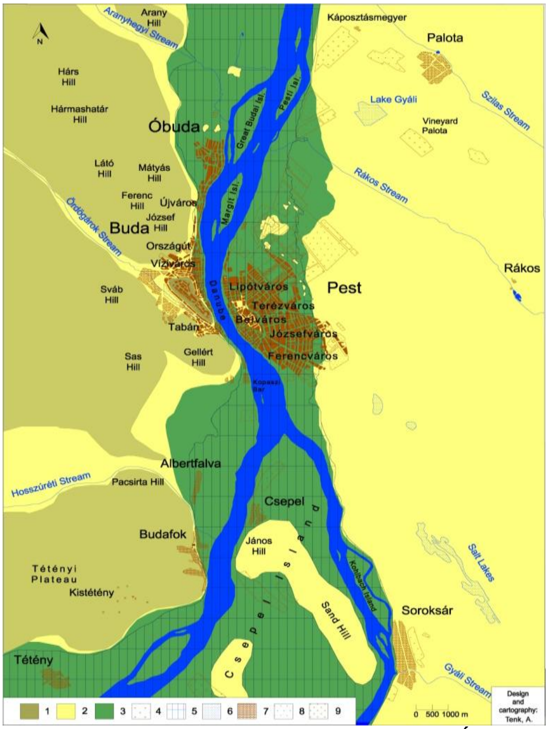

Fig. 6 The largest flooded area in the surroundings of Pest, Buda and Óbuda in March 1838 (Legend: 1 = hilly area; 2 = plain; 3 = floodplain; 4 = garden, vineyard; 5 = flooded area; 6 = marsh, swamp; 7 = settlement 8 = forest, meadow; 9 = cemetery)

The flood damage of settlements can be analyzed by SQL queries. First, a database was created, and the queries are executed by linking the data records with map geometry. When clicking on one of the table rows, the related geometric object will be displayed. The reverse is also possible, when clicking on a geometric element, the corresponding row will be selected, and its data content can be examined. This widespread GIS analysis method allows rapid inquiries on settlement damages, and fast processing and analysis of the obtained data.

Information on the extent of flood damage in a specific city quarter can easily be obtained from the database associated with the map objects. During the analysis, we first selected settlements where more than 75% of the houses remained intact, i.e. with a ratio of destroyed houses less than 25%. The match list revealed that most of the intact houses were located in Tabán, Víziváros, Országút, Budafok and Soroksár. These settlements were mainly situated in the flood-free areas of the Buda Hills. In case of settlements that had some areas on the flood plain, the damage was much more serious. There were several other examination methods beyond the above.

During our research, a query was executed on villages with more than 75% of their houses destroyed. The results showed that three villages were almost completely destroyed. The drastic destruction in Ferencváros was mainly caused by the poor quality of buildings.

Another examination analyzed areas of Pest where the ratio of intact houses exceeded 60%. Results showed that the most severe damage occurred in Ferencváros, Józsefváros and Terézváros – with more than three-quarters of the buildings destroyed or damaged – while the city centre and Lipótváros suffered less. This happened partly because the two latter parts of the city were built on higher grounds, and also because the buildings were of better quality, e.g.: important public buildings, aristocratic palaces etc. On the contrary, the poor-quality one-storey adobe buildings in Ferencváros and Józsefváros collapsed like houses of cards (Lászlóffy, 1938) **(Fig. 7)**.

The analysis shows that there were significant differences in the extent of damage caused by the flood. Out of the three largest settlements, Buda has suffered the least damage. This happened because the major part of the city was built on mountainous areas that were not affected by the flood. Óbuda and Pest were damaged to a similar extent, because both settlements were built within the present floodplain of the river, and the expansion of Óbuda in higher areas only started in the second half of the 19^{th} century.

This observation should be taken into consideration even today. Probably owing to global warming, floods become more frequent and water levels get higher in Hungary, threatening houses in the floodplain areas. While the highest water level of the record breaking 2006 flood was 860 cm in Budapest, in 2013 a new record of 891 cm was set. Despite the tendency described here, people wish to build houses right next to the river in the Római Bank section of Óbuda – creating a challenging problem for flood controllers.

When examining the ratio of intact houses, it is interesting to note that – although the level of destruction was the same in Pest and Óbuda – twice as many houses remained intact in Pest than in Óbuda. A probable explanation for that could be that Pest had higher quality houses that were able to withstand the flood more effectively.

The examination of the settlements around Pest and Buda also shows interesting results. The southern villages of Albertfalva and Csepel had suffered the greatest damage, while not a single house was destroyed in Soroksár. The next settlement is Budafok, where almost three quarters of the buildings remained intact. However, all of the destroyed houses here were built within the floodplain area of the Danube.

The comparison of the extent of damage in different districts of Buda, Óbuda and Pest also shows noteworthy results. In Pest, 34 out of 100 destroyed houses were located in Ferencváros, and 29 in Józsefváros. The main reason for that could be that in these districts, most houses were poor-quality, one-storey buildings that were easily demolished by the water (Lászlóffy, 1938).

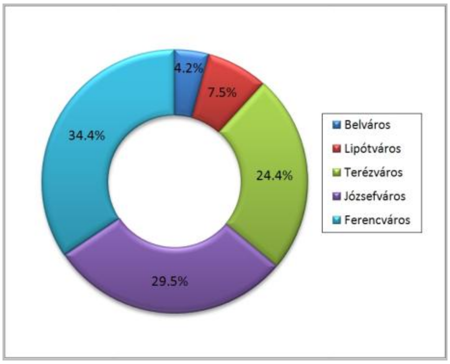

Fig. 7 Ratio of houses demolished by the flood in Pest (%)

Moreover, these two districts still lie in the deepest part of Pest, and therefore the flood could cover the houses up to the roofs. **Fig. 5** shows that these two districts – located in the area of the Paleo-Danube beds – were covered with the highest water. By contrast, the highest ratio of intact houses was to be found in Belváros and Lipótváros. As both districts were built in the highest areas of Pest, not all buildings were covered with water. Furthermore, these houses were of better quality, and could withstand the flood longer. The examination of the Buda area shows that the largest damage occurred in Újváros (Lászlóffy, 1938). This was partly due to the fact that this district lies in the lowest part of Buda, within the floodplain area. It is also worth noting that the floodplain and the endangered areas were mostly inhabited by people of low social status, and therefore authorities did not want to invest in the flood protection of these areas. In Óbuda, the flood protection possibilities were even more limited, because the settlement belonged to the royal chamber with only restricted independence **(Fig. 8)**.

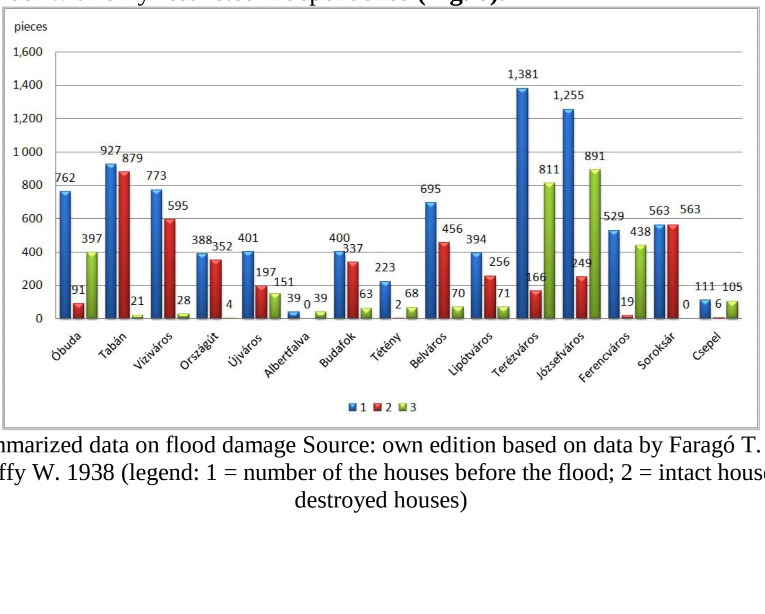

Fig 8 Summarized data on flood damage Source: own edition based on data by Faragó T. 1988 and Lászlóffy W. 1938 (legend: 1 = number of the houses before the flood; 2 = intact houses; 3 = destroyed houses)

3.3 Pest-Buda: the 2nd Military Mapping Survey

The 2nd Military Mapping Survey of Hungary was carried out between 1829 and 1866. The survey sections were produced at a scale of 1:28800, while the detailed maps (Spezielkarte) of Hungary were drawn at a scale of 1:144.000. Pest-Buda and the surrounding area are depicted on pages 50/32 and 51/32, completed in 1860–1861 (Fabók, 2005). The map from 1860–1861 illustrates the restored settlement structure **(Fig. 9)**. It is interesting that in this map, the island called Pesti Island is connected to the main land, and that the map does not mark Kopaszi Bar, one of the main causes of the Great Flood. The size of the settlements had grown since the 1st Military Mapping Survey, with Pest still expanding within the floodplain area. The extension towards north is significant, and also new settlements were established, e.g. Újpest, Angyalmező. Buda and Budafok had expanded towards the mountains, while the spreading of Óbuda continued mostly in the floodplain area.

The map shows that Csepel was rebuilt at a new location, on the flood-safe II/a Pleistocene terrace. There were some objections against the relocation of the village (because of the unfair land distributions), but the new village was almost finished by the autumn of 1839. The new village of Csepel, with its chess table layout, shows all the features of an artificially designed settlement (Kubinyi, 1961). Meanwhile, Albertfalva and Tétény were rebuilt in their original locations.

4. CONCLUSIONS, CONSEQUENCES

The city of Pest recovered from the flood damage within only four years. Based on the official data, 1164 houses were rebuilt between 1838 and 1841, but the real number is possibly higher. According to the new architectural regulations, the main walls of the buildings had to be made of stone or brick, while the use of adobe was restricted (Nagy, 1975). Furthermore, city leaders decided to act against possible flood damage. As a result, river regulation plans were set up and the implementation started on the capital section of the Danube. In February-March 1876, Budapest and its surroundings were threatened again by another dangerous and prolonged flood, but thanks to the regulation, only minor damage occurred (Lászlóffy, 1938). Except for Csepel, the destroyed settlements were re-built after the flood in their original locations, within the floodplain area. However, flood control works were implemented, and the beds of the Paleo-Danube have been filled. Consequently, later floods (e.g. in 1876) could not cause such damage as before.

5. RESULTS

In sum, out of the three cities forming now Budapest, the greatest damage was suffered by Óbuda and Pest. The most severe destruction occurred in Ferencváros, Józsefváros and Terézváros, while Belváros and Lipótváros suffered the least. In Buda, the buildings of Újváros were destroyed the most and also severe damage occurred in Tabán, Országút and Víziváros. As for the villages around Pest-Buda, Csepel was almost completely destroyed with only a few houses spared, while Albertfalva was fully demolished. One of the most important geographical reasons for such a destruction is that settlements worst affected by the flood were situated in the flood plain. However, it is worth noting that houses of good quality could withstand the pressure of the icy flood, while buildings of poor quality collapsed quickly **(Fig. 10)**.

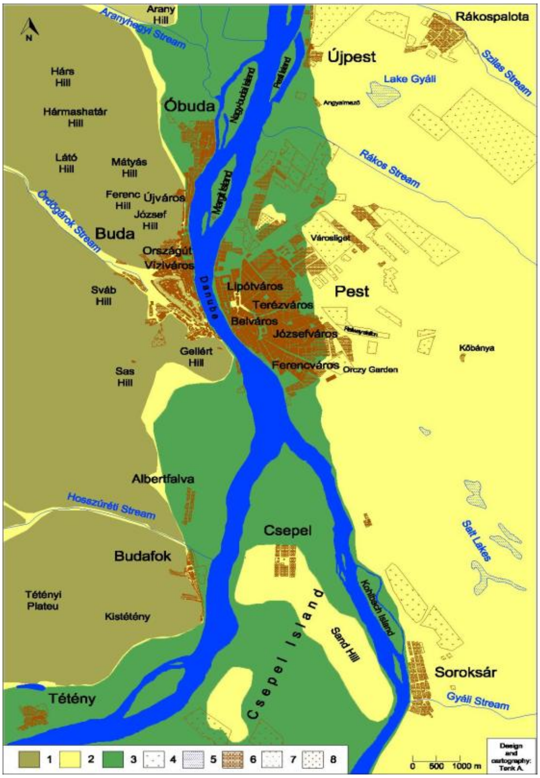

Fig. 9 Pest, Buda, Óbuda, according to the 2nd Military Mapping Survey (legend: 1 = hilly area; 2 = plain; 3 = floodplain; 4 = garden, vineyard; 5 = marsh, swamp; 6 = settlement 7 = forest, meadow; 8 = cemetery)

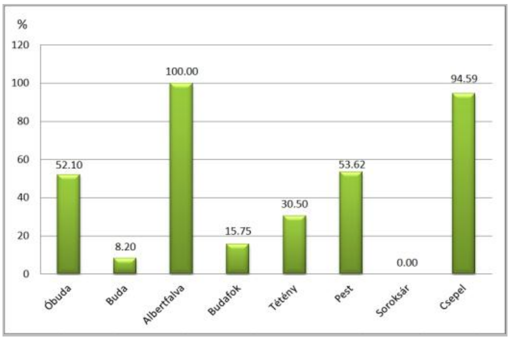

Fig. 10 Ratio of houses demolished by the flood (%) Source: own edition based on data by Faragó T. 1988

We know from historical descriptions that the water level reached even 2-3 metres in the former Paleo-Danube beds in Pest. These beds also played an important role in the quick spreading of the flood. However, there were many dry terrace remains in the area of the flooded Pest, where people could find shelter from the catastrophe. This fact should not be overlooked by today's flood controllers, as flood levels seem to be rising, while more and more houses are built on flood plains.

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