EXCERPT

presenting the results of the flooding model created on the basis of the Danube River Forest-oriented Forecast Study

created based of the contract under the name „Data processing and sample flooding model" (reference number: HUSRB / 1903/11/0070 / PRAG_SER02), within the framework of the project called „Improving Floodplain Forest Management along the Danube in the HU-SRB cross-border country area" (ref. no.: HUSRB/1903/11/0070)

Created by: Gábor Jäger, sole trader
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1. PURPOSE OF THE STUDY ELABORATED WITHIN THE FRAMEWORK OF THE PROJECT

The section of the Danube in the border area of Hungary and Serbia belongs to the most flood-prone areas of Europe. Due to the climate change, the frequency and the height of floods is expected to increase. The flood waves significantly affect numerous forest management activities connected to the floodplains and wetlands along the Danube. The planning of work operations (forestation, felling, wild game management) and activities of public interest (eg. nature-based tourism, hunting and fishing) in the areas exposed to flood risks, under the given conditions depends on the rate of change of water level, local circumstances and the knowledge of possibilities tied to the flood events.

The purpose of the study named “Danube River Forest-oriented Forecast Study” was to lay the foundation to maintain and develop an efficient forecast and warning system for flooding in floodplain forests.

2. CRITERIA OF SELECTION OF THE PILOT AREA

In the study, a representative pilot area managed by the ADUVIZIG was defined. The pilot area was chosen to be suitable to demonstrate the flooding of inundation forests, as well as to illustrate the measures pertaining to the analysed area, from the aspect of both forest management and hydrology. Besides the priority aspects of forest management, other practical factors also played a role in the selection of the pilot area.

These practical factors were the following:

- after the closing the project, the achieved results should be made available for use as soon as possible,
- the vicinity of the Danube,
- the vicinity of the flood protection levee,
- appropriate accessibility,
- appropriate survey conditions.

Considering the aforementioned aspects, the decision was made to choose the forested land plots Dusnok 20/A, Dusnok 20/B, Dusnok 20/C and Dusnok 20/D as a pilot area.

3. CHARACTERISTICS OF THE PILOT AREA

The tree stock in this area is young (2-10 years), which allows to take measures in a young-aged forest if required, depending on the results of the project.

The above forested land plots are bordered by the Danube to the west and the flood protection levee to the east. Because of this, the area is easily accessible from the water by boat, from land by main road no. 51. and by service road of the M9 expressway, as well as from the north and south using the flood protection levee.

The examined area can be considered as two separate parts which are divided by a dirt road which runs perpendicular to the axis of the Danube. The southern part has a rectangular shape, while the part which lies north of the dirt road is triangle-shaped, narrowing towards the north corner. The preliminary on-site inspection revealed a planted forest, grown in rows with diverse age structure and height differences reaching 3-4 m at places. The eastern boundary of the area is a short section of the primary flood protection line no. 0301. Next to the levee km post 23+600, on the protected side, there is an EOMA benchmark (Egységes Országos Magassági Alaphálózat – Uniform State Network of Elevation Points). Having in mind that the trees haven’t grown too large in this recently planted forest area, there is a possibility to use a quicker survey technique.

Figure.: 1. Forested land plots and the surveyed area *(author's work)*

4. METHODOLOGY OF THE FIELD SURVEY

The area consists of predominantly planted forests of different species and age class. Considering the tree canopy coverage, the equal row distance and the undergrowth, an installation of a GNSS base station was carried out in the levee km post 23+000 and 24+000, whose position was determined using the EOMA benchmark no. 182319, after which the elevation was controlled by linear leveling.

Figure.: 2. The area to be surveyed (author's photo)

The detail survey was executed with a GNSS RTK rover, by staking out the virtual grid covering the area to be surveyed with a resolution of 25*25 m and measuring the spatial data of the grid points. At the locations which don't overlap the grid points, but have an importance because of the microrelief conditions, the decision about the further detail survey had to be made on the spot, during the marking and measurement tasks.
Before surveying the area, the densification of the horizontal and vertical base points has been executed. In the case of horizontal base point densification, the determination of horizontal coordinates of the levee km posts 23+000 and 24+000, set as stationary base points, is carried out by means of a GNSS receiver, using RTK mode, with an observation time of 180 seconds. During the densification of vertical base points, the determination of the elevation of the two levee km posts was realized from the nearby EOMA benchmark by means of linear leveling.

Figure.: 3. Leveling (1. onepointsurvey.com)

Relying on the two determined base points, the survey of the area was conducted with GNSS receivers, using a base and rover method. In the base and rover method, the GNSS receiver, serving as a base station, has to be set on a base point with known horizontal and vertical coordinates, while the detail points can be measured with a moving rover GNSS receiver. The base station transmits a correction signal to the rover over UHF radio in order to provide the required accuracy. The advantage of the base and rover method is that this method provides a slightly better relative accuracy with a more stable fixed position. A further advantage is that the data correction fee is only charged for horizontal (and occasionally for vertical) base point densification. Its disadvantage is that the range of the UHF radio in an open field is limited to about 3 km. *(2. Busics 2011)*

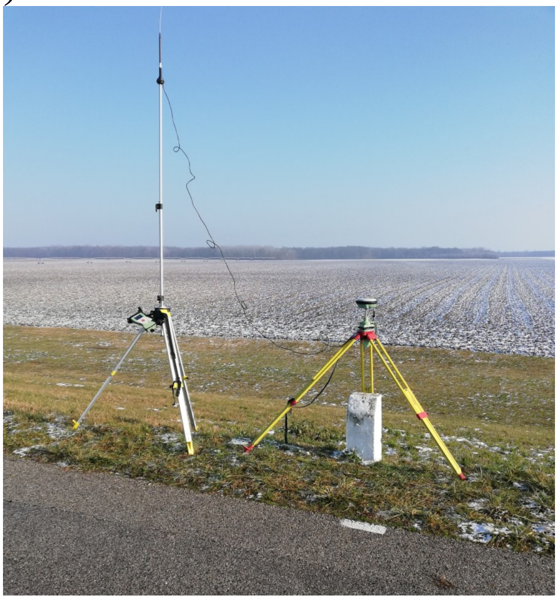

Figure.: 4. Base station set on a levee km post with known horizontal and vertical coordinates (author's photo)

The field survey was conducted in a grid of 25x25 meters. During the measurement, the square grid prepared in advance was marked successively, after which the elevation of the grid points was measured. Besides the field survey of the grid points, the breaklines identified on the spot (peak line and bottom line of slopes, terrain breaklines) were also surveyed.

5. METHODOLOGY OF CREATING FLOODING MODELS

Based on the survey results, the flooding model of the area can be created. The purpose of development of a flooding model is to enable a map interpretation of a flood inundation belonging to a specific stage or water level, based on the digital terrain model.

The two commonly applied methods of creation of digital terrain models (surface creation) are the quadratic (raster) and the triangular (TIN) projection.

In raster visualization, the surface is projected from elevation values of regularly distributed grid points. The calculation of the elevation of any other points outside the grid points is possible with interpolation. The accuracy of the surface depends on the cell size. The advantage of the raster modeling is that it enables a fairly easy storage of great data volumes. However, its disadvantage is that it doesn’t appropriately present the contour lines of the surface because of the equidistant sampling.

As a consequence, the raster data models are more suitable for small-scale mapping and effective visualization tasks.

Creating a TIN (Triangulated Irregular Network) surface is based on forming the most compact network of triangles called the Delaunay triangulation. In the Delaunay triangulation method, the triangles which form the surface are defined in a way to maximize the smallest angle of the triangles. Hence this method is avoiding sliver triangles, it well preserves the original terrain geometry.

Consequently, the TIN surface is a representation of the surface with closed, three-dimensional triangle faces which are connected to each other. The continuity of the surface is ensured by the possibility to calculate the elevation of any points within the three-dimensional triangle face with interpolation. The TIN surface preserves the position and shape of the terrain. The contour lines of the terrain (ridges, valleys) can be defined as breaklines, so these are projected as continuous triangle edges in the TIN mesh. The discrete points (peaks, depressions) can be projected as triangle vertices. *(3. Szatmári et al 2013)*

The flooding model was created in two versions. In the first version, the model had to be developed using the available base dataset. In the second version, the base geometry data had to be corrected with the dataset acquired by the survey.

In the base dataset, the elevation data were derived from a DDM5 digital terrain model. The digital terrain model has undergone multiple corrections and partial updates since its first release. The first version was developed based on the contour lines of topographic maps created between 1979 and 2000. The base dataset containing the contour line drawings is under continuous improvement with the help of stereophotogrammetric evaluation. *(4. Lechner 2021)*

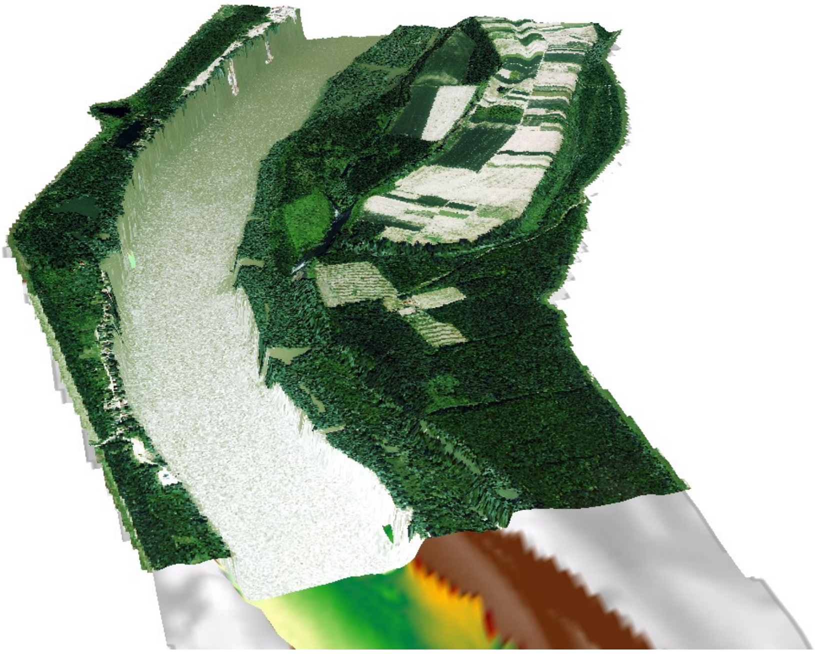

Figure.: 5. Raster image of a digital terrain model with an orthoimage overlay (author's work)

The creation of the second geometry version was carried out in two steps, according to the method described below.

As a first step, the surface model was built using the measured data. During data acquisition, the elevation data was measured in a regular grid. It was required also to carry out the measurement of points which describe the surface, together with contour lines (peak line and bottom line of slopes, high points and low points). Given the character of the survey, the surface was created with an irregular triangular mesh. Besides the measured points, the contour lines drawn from those points were also used while defining the surface. After adding the input data, the editing of the surface was executed. During the editing, the edges of the automatically-generated triangulated irregular network were needed to be swapped according to the rules of interpolation. When the breaklines were added to the surface, the triangle edges crossing those lines were automatically swapped, as the interpolation across the breaklines was not possible. In the second step, the developed model was inserted into the base geometry.

Within the scope of data processing, a surface model was created. During the surface modeling, the continuous surface was developed based on elevation measured at discrete points. The continuity of the surface was an important base condition for the further phases of the modeling process.

The processing started with importing the measured points into AutoCAD Civil 3D. The points were imported in the No, E, N, Z, D format (Point number, Easting, Northing, Elevation, Point description). Considering that besides the measurements in a regular grid, the breaklines identified in the terrain were also surveyed, the creating of a TIN surface was required.

The surface was developed once it was defined with measurement points. While creating the surface, the software automatically generates the triangulated network (following the rules of Delaunay triangulation). After generating, the user is allowed to modify the TIN surface: points can be added or erased, as well as edges can be added, erased or swapped.

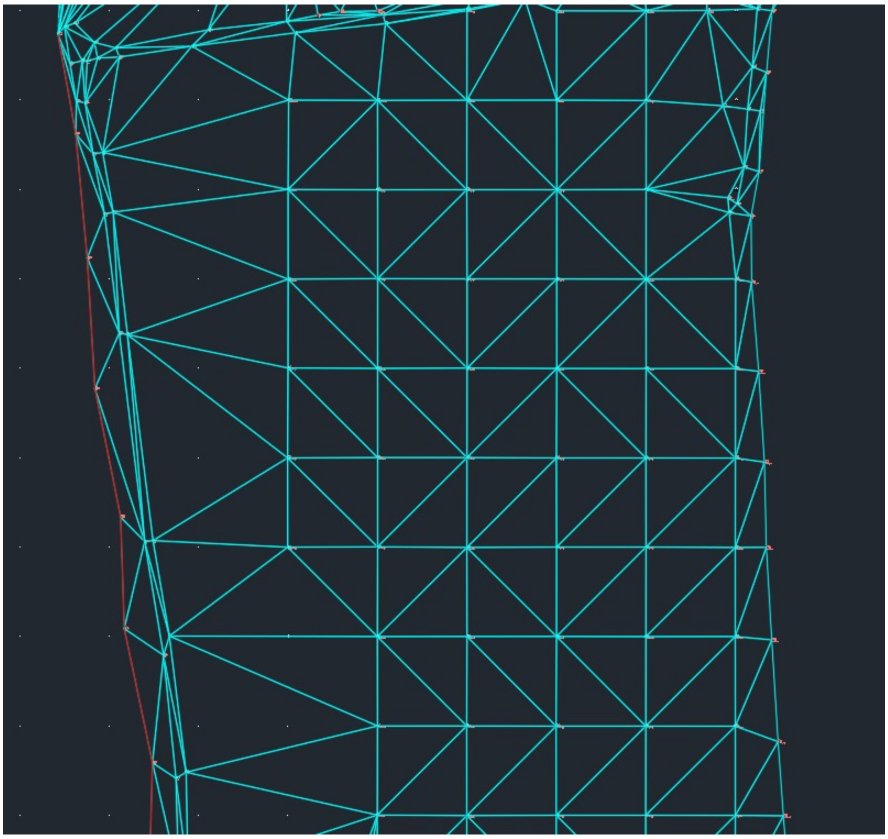

Figure.: 6. Triangle mesh of a TIN surface (author’s work)

The editing of the surface was executed according to the aforementioned methods, aiming to describe the real shape of the terrain in the best possible way. The created and edited surface can be exported from the AutoCAD Civil 3D in GEOTIFF format, which also allows importing and editing in other softwares.

For the later visualization, the TIN model was converted into raster data format.

When presenting the results of the modeling, the highest obtainable vertical resolution of the flooded area, considering the given survey dataset, was strived for. Furthermore, the model had to consider the phenomenon according to which the filling of the lowest-lying parts of the surveyed area occurs simultaneously with the process of water stage rise in the main riverbed, because of the connection of the floodplain to oxbow lakes, sidearms and groundwater flow.

6. PUBLISHING OF THE OBTAINED RESULTS

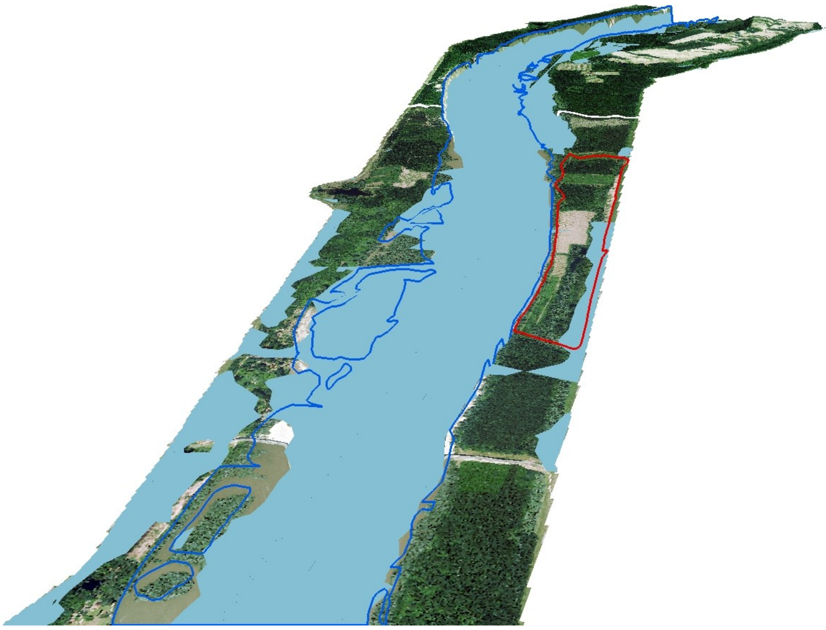

Figure.: 7. Visualization of flooding on the base geometry (author's work)

In the framework of data processing, the flooding models were created for both geometries. The base geometry, which is created based on the contour lines, shows that the water appears in the examined inundation area at a 490 cm stage on the Dombori gauge. When using the geometry based on a detailed survey, it is visible that the water appears in the floodplain depressions already at a 190 cm stage on the Dombori gauge.
The figures shown below depict the extent of flooding at a 600 stage on the Dombori gauge on the base and the surveyed geometry, respectively. The visualization of flooding on the surveyed geometry illustrates the inundation of the low-lying areas which doesn't appear on the base geometry.

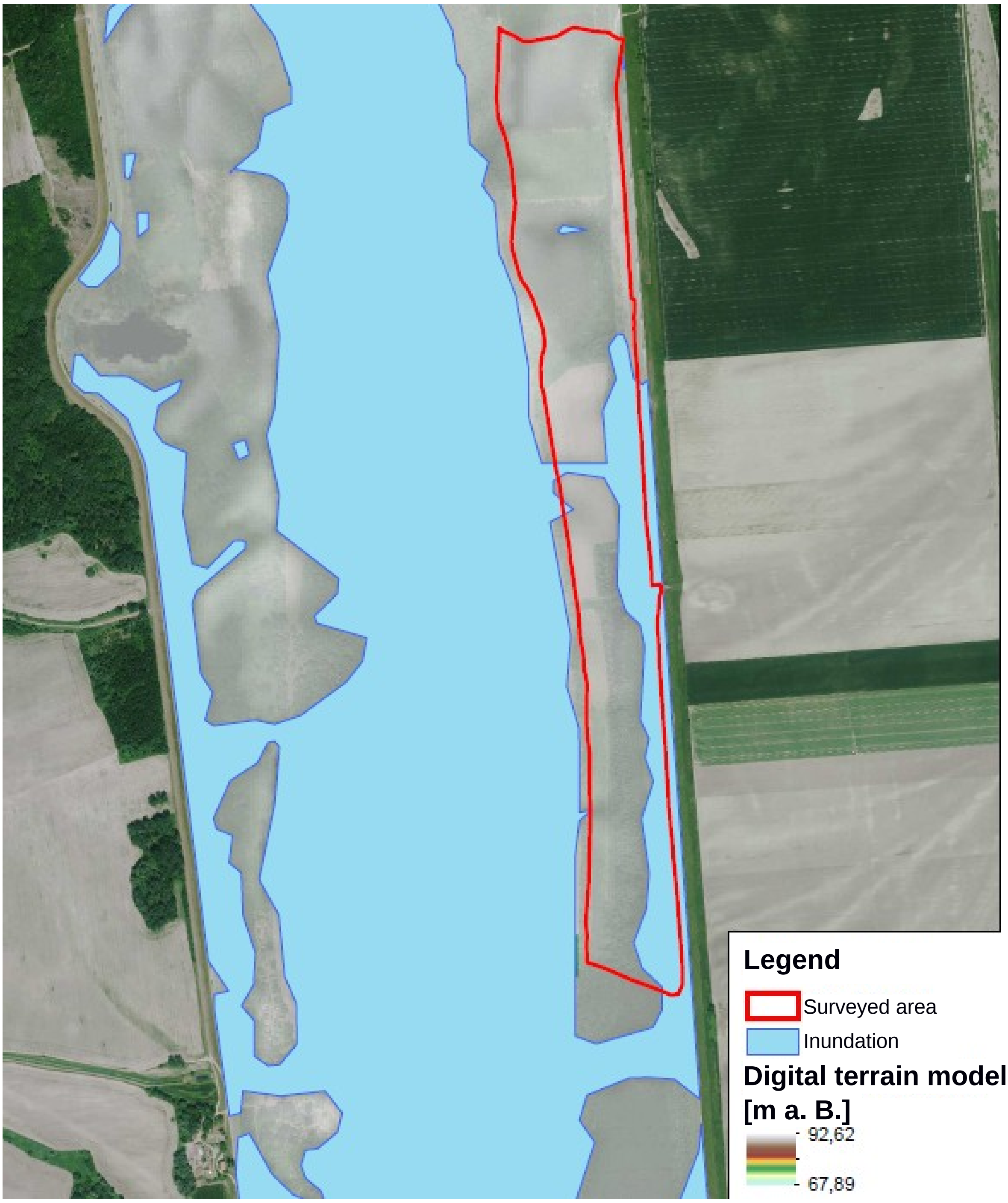

Figure.: 8. Visualization of flooding on the base geometry at a 600 cm stage on the Dombori gauge (author’s work)

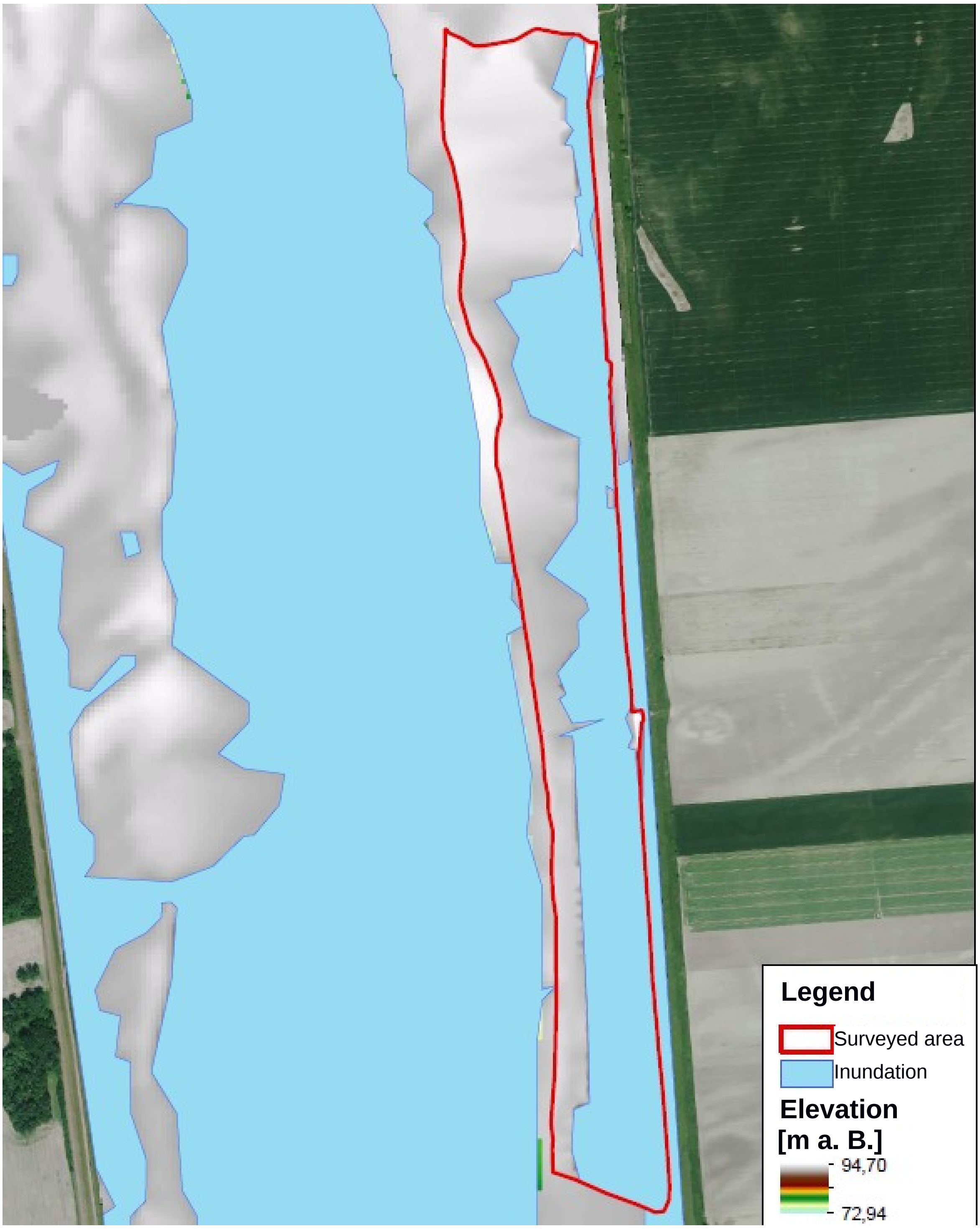

Figure.: 9. Visualization of flooding on the surveyed geometry at a 600 cm stage on the Dombori gauge (author’s work)

Sharing of the results is a task of high-priority as well. According to the users’ needs, as well as to the engineering practice, it is necessary to create a demonstrative website to present the results obtained with the flooding model presented in plan view, using multi-color graphics and taking into consideration the UX/UI (user experience / user interface) design criteria.

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