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HYDROGEOMORPHOLOGICAL METHOD OF FLOODPLAIN DELINEATION

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ABSTRACT

This article introduce the hydrogeomorphological GIS based method of floodplain delineation based on elevation data and flood heights increasing downstream. The results were compared with floodplains derived from soil maps and with boundary mapped using GPS points. The advantage of this method is the low demands on the input data and the ability to define the floodplain of a large catchment area. Resulting floodplain maps present possible flooded area and can be used in preliminary flood risk assessment and landscape planning.

Key-words: *Floodplain, mapping, GIS, hydrogeomorphological method.*

1. INTRODUCTION

The purpose of this paper is to present a hydrogeomorphological GIS-based approach to genetic floodplain delineation. Floodplain is delineated as a distinct geomorphic landscape unit and it represents potentially flooded area of extreme flood events without considering embankments and dikes. It is part of alluvial plain that would be naturally flooded in the absence of engineered interventions or in the case of their failure.

Presented method enables fast and relatively accurate floodplain delineation applicable for big river basins. The required data inputs are only digital elevation model (DEM) and river polyline layer. Tree main parameters were used in the model: flood heights, flood width and stream gradient. Progressive change in the flood heights and width of the floodplain were calculated based on the distance from the source. The equation for the calculation was derived from data of the gauging stations in the gauging stations in the Czech Moravian geomorphological region. Model outputs were compared with the floodplain delineated from soil maps and we verified the accuracy of the model using GPS control points measured in the field.

2. FLOODPLAIN DEFINITION – GENETIC AND HYDRAULIC FLOODPLAIN

Every field of physical geography defines floodplain differently. In pedology it is an area where hydromorphic soils are formed in alluvial deposits (Ložek, 2003). Geomorphologists define the floodplain as a flat valley floor adjacent a stream or river made by alluvial unconsolidated sediments transported and deposited by the river and usually experiences flooding when the river floods (Demek, 1988). Geomorphological and pedological definitions represent genetic floodplain, which have been dominantly formed or reformed by contemporary processes (Nanson & Croke, 1992). Valley slopes and terraces form the natural boundary of the floodplain. Hydrologists and engineers define the floodplain as the surface next to the channel that is inundated once during a given return period regardless of whether this surface is alluvial or not (Ward, 1978). Nanson and

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Croke (1992) term this area hydraulic floodplain. Geomorphic history does not play a role in this definition. Hydraulic floodplain boundary may be similar like genetic floodplain boundary for natural rivers, but probably will be very different for human changed river systems with river regulation and embankments for flood protection.

Genetic floodplain was mostly formed before direct human disturbance and it represents potentially flooded area when technical flood protection fails. Dykes and protection walls protect man and his property to a planned upper limit, which may always be topped by extreme floods. If this limit, the so called design flood is topped, damages behind the flooded dykes tend to be extremely high.

3. USE OF SOIL MAPS FOR FLOODPLAIN DELINEATION

Accurate soil maps, properly interpreted, will give a good estimate of land subject to flooding (Cain & Beatty, 1968). The use of detailed soil maps for delineation of the floodplain areas is fast and economical. Floodplains are distinct landscape units that contain specific kinds of soils. Very good indicators of floodplain area are Fluvisols - weakly developed soils, formed predominantly on the water borne sediments associated with the flood plains rivers (Ward, 2008). Fluvisols have unique properties due to the fact that they have been inundated periodically throughout the geologic history of their development (Cain & Beatty, 1968). Witner (1966) reported that the boundary of alluvial soils indicated by the soil survey corresponded very closely to the edge of the fifty-year floodplain.

In urban or highly developed areas, human works alter the extent and area of flooding. Land is protected by levees or interrupted by embankments. Floodplain is no longer flooded periodically and is often used for agriculture, industry and housing. In that case, Fluvisols are the memories of the landscape and they represent potential flood prone area in case of flood protection failure.

There are several soil maps available in the Czech Republic. We used two soil maps to delineate floodplain, one in the scale of 1: 50 000, covering the whole country (**Fig. 1**) and the second, map of valued soil-ecological units (BPEJ) in the scale of 1:5 000, but these detailed map cover only agricultural land.

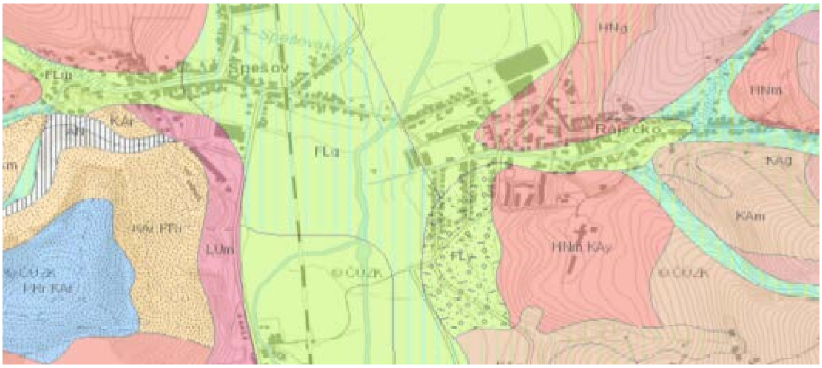

Fig. 1 Floodplain outlined by Fluvisols (FL) on the Soil map 1:50 000.

4. HYDROGEOMORPHOLOGICAL METHOD OF FLOODPLAIN DELINEATION

4.1. Input data

Required input data consist of the following:

- Digital elevation model (DEM),
- River Polyline Layer,
- Estimated flood heights.

DEM was created from contour lines with index contour line interval 2 m or 1 m depending on the character of the relief. The source of contours and River Polyline was Fundamental Base of Geographic Data of the Czech Republic (ZABAGED® 1:10 000). Heights of the flooding were estimated using the regression function based on data from surrounding gauging stations.

4.2. Delineation parameters

Floodplain as a landform has a special morfometric a geographical attributes that can be used for its delineation. We used the following parameters:

a) **Flood heights** Floodplains were formed by floods and so we can expect floodplain to some vertical height above river bed. Possible floodplain heights above the river bed rises with increasing discharge.

b) **Width of the floodplain**. Floodplain adjacent to the river or stream. Possible floodplain width extends with increasing discharge.

c) **Slope and stream gradient.** Floodplain is a flat landform; we can expect slope up to 4%. Stream gradient indicates river type. Some river types commonly form floodplains. Rivers with gradient above 4% usually do not form floodplains.

Relative height of flooding above a stream bed depends on flood discharge. The correlation analyses indicated that flood discharge is highly correlated with catchment area and distance from the source (**Fig. 2**). These relationships can be used to estimate the maximum flood heights for each point on the river. The correlation between the discharge and the distance from the source is slightly weaker, but we used this, because the DEM was not available for whole catchment.

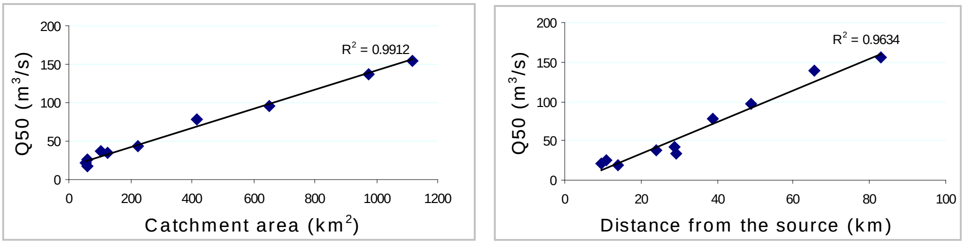

Fig. 2 Strong relationship between 50-year flood discharge and catchment area (on the left) and distance from the source (on the right) in the river Svitava catchment.

We explored the relationship between 50-year flood stage and distance from the source to estimate the height of the flooding. 50-year flood stage is the stream level of extreme danger calculated at Czech water-gauging stations and corresponds to 50-year flood discharge (**Fig. 3**). There are only tree gauging stations with 50-year flood stage calculated in the Svitava catchment, so we used data from the entire geomorphological region – Czech Moravian System. With increasing distance from the source initially flood water level is growing rapidly, but this growth gradually decreases. This relationship is good expressed by power function and we used this function to estimate the maximum height of flooding for each point on the stream.

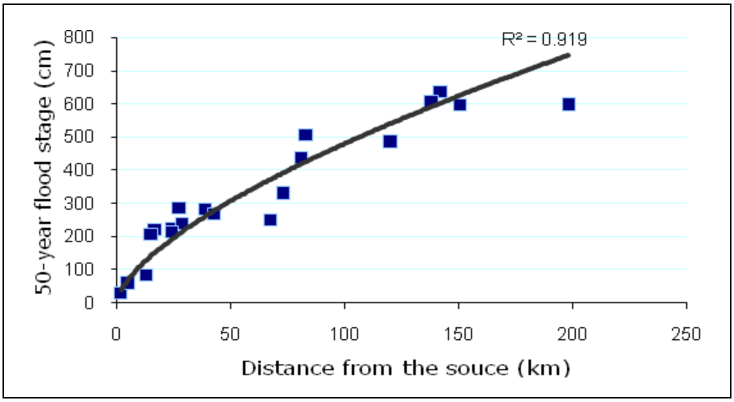

Fig. 3 Change of 50-year flood stage with increasing distance from the source. Data were used from gauging stations in the Czech Moravian geomorphological region.

The maximum possible width of the floodplain increases together with flow rate downstream. We took this into account when setting the width of the IDW interpolation to calculate flood elevation. Streams were divided into several categories and the width of the output IDW grid layer was based on the distance of station points from the source. For example for small streams (< 10 km), we didn´t suppose the width of the floodplain more than 200 m.

Table 1. Categories of the maximum floodplain width increasing downstream

Distance from the source	Maximum width of the floodplain
0 – 10 km	200 m
10 – 20 km	500 m
20 – 50 km	1000 m
50 km <	4000 m

Floodplain is a flat landform. We can expect slope inclination up to 4%, although in large scale we could find a microrelief with steeper inclination.

A classification system for natural rivers (**Fig. 4**) was presented by Rosgen (1994; 1996). The longitudinal profile serves as the basis for breaking the stream reaches into slope categories that reflect profile morphology. The gentle-gradient stream types (C, DA, and E stream types with slope < 2%) usually form broad, well defined floodplains. Type D represents braided rivers (slope < 4%). Type B is moderately entrenched witch narrow valley and moderate gradient (2 to 4%) Small, narrow pockets of floodplain may occur. The Aa, A types are steep (slope > 4%), entrenched, high energy streams witch V-shaped valley. F and G types are entrenched or deeply incised, and confined, gently to moderate gradient rivers (slope < 4%) with little to no developed floodplain. Exceptions occur infrequently, where values of the slope may be outside of the range for a given stream type.

Stream type indicates the presence of the floodplain and can be predicted from the river bed slope. Stream gradient over 4% points to river type without developed floodplain and these were removed from floodplain delineation.

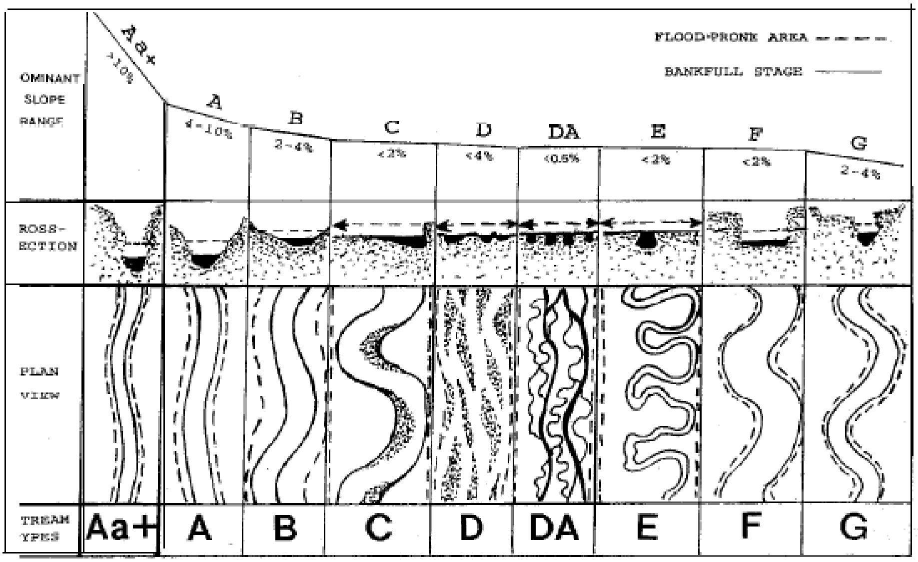

Fig. 4 Longitudinal, cross-sectional and plan views of major stream types (Rosgen, 1994).

5. FLOODPLAIN DELINEATION L IN ARCGIS

5.1. Data pre-processing

We can calculate raster of accumulated flow for each cell using the Flow Accumulation tool in ArcHydro Extension. Catchment area is than extracted to each point and it can be used to calculate progressive flood heights. We did not have DEM for whole catchment, so we used the distance from the source instead. Using distance from the source is less accurate, but reliable enough for regular dendritic drainage system.

Route was created from the stream lines using the Create Route tool in Linear Referencing toolbox to calculate cumulative length from the stream source. We used stream ID to set the route identifier field and From/To Measure Field method was applied using ID of source and ID of confluence from attribute table to create right downstream orientation of the stream route.

The point layer was generated along the stream polyline at an equal distance (100 m) between points using Station Points function in the ET GeoWizards extension. Distance from the source was stored in attribute table and elevation was extracted to points from the DEM using Extract Values to Points function. Expected maximum **flood heights (H)** above river bed increases downstream and it was calculated for each point using this mathematical formula: $H = 0.222D^{0.801}$. Formula was derived from the hydrological data from the Czech gauging stations. D is distance from the source. **Flood elevation** was calculated as the sum of flood heights and altitudes for each station point. The point layer was input to the IDW interpolation in ArcGIS to create the maximum flood elevation raster. We used method described by Hartvich & Jedlička (2008) to create raster of progressive flood elevation, where relative height above river is increasing downstream, but the relative height above river stays same in direction perpendicular to the river polyline.

5.2. Model for floodplain delineation

We created model with Arc GIS ModelBuilder to automate the workflow of floodplain delineation. Inputs to the model are only (1) station points layer with the flood elevation and stream gradient attributes (2) DEM.

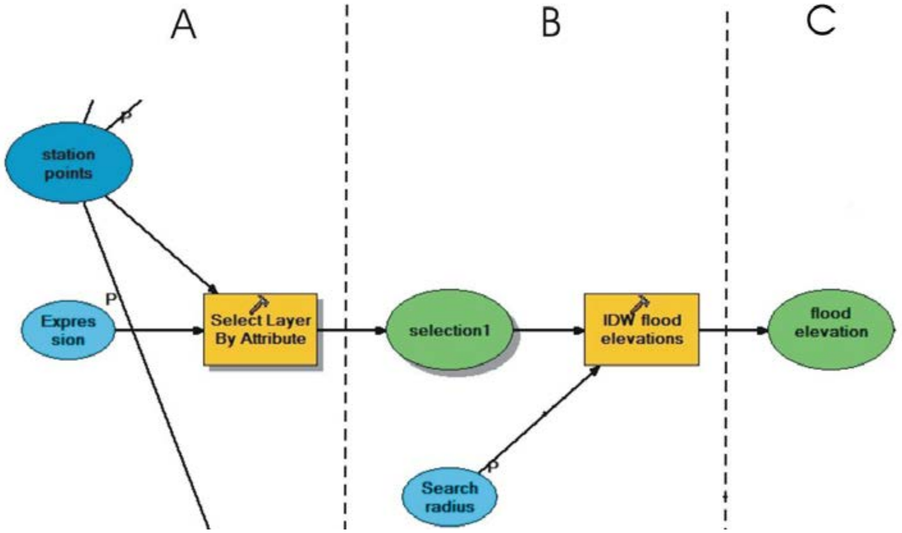

Fig. 5 Model for floodplain delineation; creation of Flood elevation raster.

Only points with a stream gradient below 4% were selected to interpolate. Station points were classified according to distance from the source to specify different radius (maximum floodplain width) of IDW interpolation (**Fig.5 A**). Interpolation was executed separately for each class (**Fig. 5 B**). Outputs were floodplain elevation rasters (**Fig. 5 C**), what was used together with DEM to perform Cut/Fill operation (**Fig. 6 D**). Output map displays terrain higher and lower than expected maximum floodplain level and negative values represent floodplain areas.

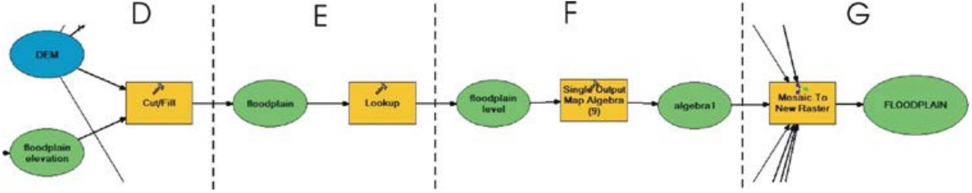

Fig. 6 Model for floodplain delineation; Cut/Fill, Lookup, SOMA, Mosaic To New Raster.

We created a new raster by looking up negative values from the volume field in the attribute table of the Cut/Fill raster (Spatial Analyst - Lookup tool, **Fig. 6 E**). Con statement with the Single Output Map Algebra was applied to evaluate cell values to true for floodplain and false for higher terrain (CON (Lookup_cutfi2 > 0, 1, 0), **Fig. 6 F**). Then we merged all output rasters (with different IDW radius) using Mosaic To New Raster tool and the final floodplain raster was created (**Fig. 6 G**).

6. ACCURACY EVALUATION

Two main factors influence the accuracy of the HGM model for floodplain delineation:

- Input data quality, especially elevation data accuracy,
- Uncertainty in flood heights.

6.1. Data quality

The accuracy of the model was influenced by the quality and scale of input contour lines (ZABAGED), which were used to create DEM. ZABAGED is a digital geographic model of the Czech Republic at the level of detail corresponding to the topographic map of Czech Rep. 1:10 000. Contour lines interval was 2 m (1 m in a flat relief).

Very small streams, especially on alluvial fans, didn´t have any valley recorded in the elevation data. Contours were almost perpendicular to the stream and this causes unnaturally wide floodplain, although the calculated flood height is very low for the small stream (**Fig. 7**). Most of these errors were removed by filtering out rivers with a gradient above 4% and longer than 500 m.

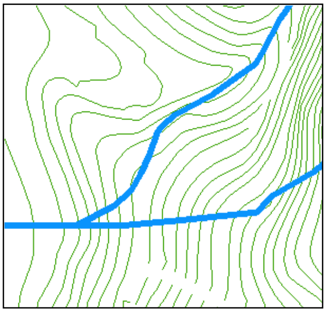

Fig. 7 Contours perpendicular to the stream.

Problem for correct interpolation was absence of contour lines on a valley bottom and their interruption on sharp terrain edges. The consequence is inaccuracy in determining the gradient of the valley floor and position of the foot of the slope (**Fig. 8).**

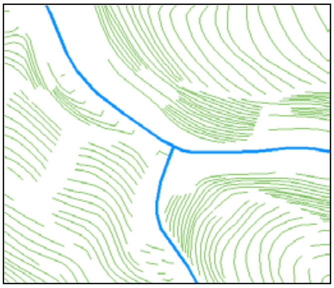

Fig. 8 Interruption of the contours.

Other errors were caused by inaccuracies in the stream layer, when polyline did not fit the valley represented by contours. Most of the errors were caused by data inaccuracy on headwaters and small streams and so we did not delineate floodplain for small streams with a length up to 500 m from the source. These small streams are not able to develop wider floodplain and if they flow through a flat landscape it is mostly a wetland.

6.2. Uncertainty in flood heights

Gauging stations measure stream stage. It is a height of the water surface above the gage zero. Discharge is calculated from stream stage heights using a rating curve based on historical measurements of flow and stream stage at the gage. Frequency analysis of peak discharges is the standard approach for defining extreme floods. Frequency analysis of the peak stage heights is unconventional, but available at some Czech gouging stations. Peak stage elevations can be derived from the peak stage heights, because altitude of the gage zero is known. We used data from 19 gauging stations (50-year flood stage heights) to calculate the regression equation to determine the variation of flood stage heights along that watercourse. At ungauged sites, uncertainties in the calculated flood heights are necessarily higher. The standard deviation of the differences in 50-year flood stages between flood heights from gauging stations and the regression equation is 40 cm. Such error is acceptable for our purpose, because such change of the water level represents only a small shift of the floodplain boundary in sloping terrain (**Fig. 9**).

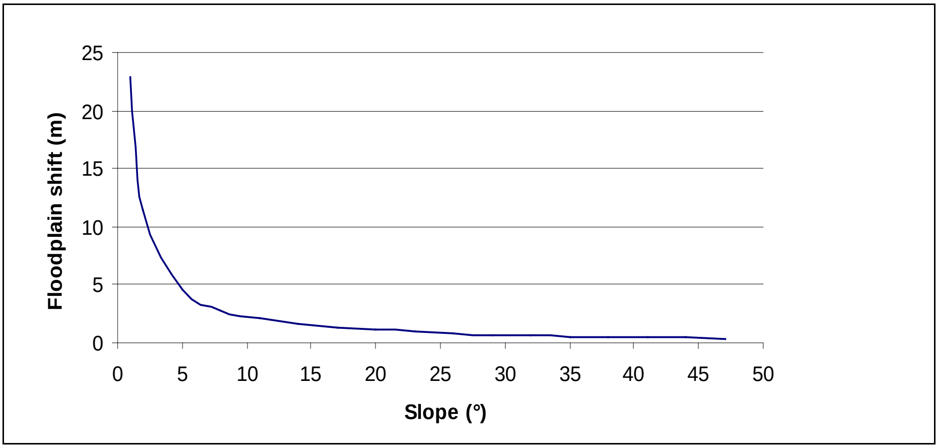

Fig. 9. Floodplain boundary shift dependency on slope gradient for 40 cm change in water surface elevation (tangent function).

Floodplain boundary delineation is much more uncertain in the flat relief then in the mountains. The floodplain boundary is often formed by gently inclined surface at the foot of a slope (colluviums, alluvial fans). This is the most difficult kind of boundary to delineate floodplain. We expected slope inclination higher than 2° on a foot slope and this slope represents only 11 m shift of the floodplain border (approximately 1 pixel) for the 40 cm change of the flood elevation.

6.3. Comparison of the HGM and pedological methods of floodplain delineation.

Real border of the floodplain was mapped in the field. We recorded floodplain boundary using a GPS on 58 control points. Distance from the points to the delineated floodplain borderline was measured using Near Tool in ArcGIS. We compared HGM method with floodplains delineated from the soil maps (**Tab. 2**, **Fig. 10**). Floodplain derived from the detailed BPEJ 1:5 000 map was less accurate than one derived from the soil map 1:50 000 and HGM, mainly because it underestimated the floodplain extend in urban area. Points which are located beyond the floodplain boundary had a significantly higher error (53,3 m) than points within (32,2 m). This was due to the fact, that floodplain is not defined in BPEJ maps for smaller tributaries in forested and urban areas.

Table 2. Distance measured between delineated border and GPS control points.

	BPEJ	Soil map	HGM
Average error	42,4 m	38,3 m	27 m
Points within error	32,2 m (30 points)	31 m (28 points)	28,9 (37 points)
Points outside error	53,3 (28 points)	45,2 m (30 points)	24 (21 points)

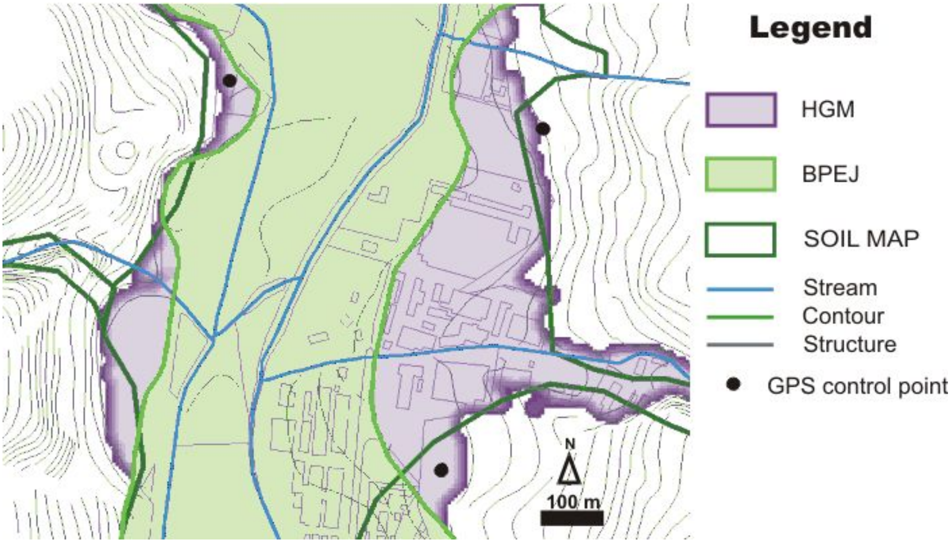

Fig. 10 Comparison of the HGM floodplain and pedological floodplains.

7. CONCLUSION

Goal of this paper was to introduce hydrogeomorphological method for genetic floodplain delineation and evaluate its accuracy and usability. The proposed HGM model for floodplain delineation is more accurate in comparison with floodplain defined from the soil maps, especially in urban area. In contrast to BPEJ agricultural soil maps, it can be used for all catchment including urban area and forested land. The model accuracy depends on the scale and quality of input elevation data for DEM creation. Used contours with 2 m interval are not accurate enough to delineate narrow floodplains along the small streams, but accuracy was sufficient for bigger streams – the average error was 27 m. The delineation process was automated in ArcGIS ModelBuilder, so it can be easily used for floodplain delineation of the whole catchment area. Floodplain maps present possible flooded area and they are important tools to be used in preliminary flood risk assessment.

Furthermore we want to explore the effect of the different elevation data on the accuracy of the model and find out how different physiographic conditions affect the flood heights.

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