

Set-up of Geometrical Network of Sustainable Streams

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Abstract – In order to set up a "hydrologically accurate" digital model of landscape, which allows identifying borders of flooded territories in the period of changes in the water level, it is important to have data in the hydrography stratum on the direction of river streams. The given issue can be solved by creating a geometrical network of sustainable water streams. The geometrical network of sustainable streams represents a mathematic model of different network structures object classes.

Keywords – ArcGIS, Geometric Network, GIS, terrain model, Topogrid, Tingrid

I. INTRODUCTION

In the process of modelling and carrying out spatial analysis of the research territory, the geographic information system (GIS) framework faces problems, which are connected with obtaining a "hydrologically accurate" surface model for identification of a flooded border zone during the period of changes of the water level, that is, for hydrodynamic calculations of geospatial projection.

The experience shows that the digital models obtained from maps, frequently produce inaccurate landscape of the territory in some parts. An example of such zones may be a riverbed with steep banks. The improvement of the quality of digital terrain models can be facilitated by using additional information on landscape and hydrography to the maximum extent possible existing in the map.

Formation of the accurate digital model is going to be carried out within the framework of a geographic information system. ESRI ArcGIS 9.3 software has been selected as the platform of the geographic information system.

Geospatial data analysis, territory visualization and analysis of surface, surface interpolation, analysis of processes has been carried out with the use of ArcGIS analytical modules: *3D Analyst*, *Spatial Analyst* and *Geostatistical Analyst*.

In order to produce an accurate digital terrain model by using the interpolation technique within the ArcGIS framework, there is a *Topo to Raster* function, which makes it possible to calculate the terrain model with much higher quality than models generated with the regular interpolation techniques. The above mentioned function includes not only spatial positioning of landscape isolines and height points, but also a layout of river networks, closed reservoirs (lakes), and local lows of landscape.

When producing the digital terrain model with a *Topo to Raster* method, it is required to have hydrographic data on the direction of river streams. The ArcGIS environment solves this problem by creating a geometric network of river

sustainable streams. The geometric network allows conducting analysis of streams in the network, the main feature of which is to define the rules of linking network elements.

The *Personal Geodatabase* format has been used to process and store input data. The value tolerance of all vector data has been defined with 0.001 m. The manual digitization was carried out in the precision scale of 1:10 000.

All geospatial data have been processed in the Latvian coordinates system LKS – 92. Transversal Mercator projection, acute longitude 24° 00"E, scale coefficient 0.9996, ellipsoid GRS – 1980, false Easting 500 000, false Northing 0 m, coordinate reading: WGS 1984 [1].

The Laucesa river serves as a "pilot territory", which is the largest sleeve of the Daugava left river bank in Latvia (basin – 728 km², including 230 km² located in Lithuania) [2].

The research, as well as the demonstration and approbation of techniques is to be carried out on the selected "pilot territory".

II. TECHNIQUES OF PRODUCTION OF GEOMETRIC NETWORK OF SUSTAINABLE WATER STREAMS

The geometric network is a mathematical model of different network structures used for modelling river water flows, it consists of the following objects – *Edge* elements and *Junction* elements [3].

The geometric network is a special type of topologic connection. Topology allows setting rules, which control spatial relations between network elements in the input data.

Edges and *Junctions* represent classes of spatial objects, included into the *ArcCatalog / Geometric_Network Geodatabase*. *Edges* are elements, the length of which directs the stream flow. The *Edges* are created from a linear class of hydrographic objects, which are topologically linked with each other and have connections only in *Junctions*. The stream in network edges is enabled through junctions. This is the way to describe the geometry of sustainable water flows in the network.

Apart from the geometric network, ArcGIS allows simultaneous formation of the logical network of the river water flow to serve as a description of the connectivity among all network elements. The logical network is represented in the attributes tables, which reveal the sequence of geometric network classes layout and their connectivity with each other. The logical network is a collection of connected edges and junctions that are continuously updated when editing the network features. The connectivity among the network elements is established in the editing process and ensures accuracy of the network modelling. The logical network does

not include real geometry; however, it provides help for functioning of the geometric network. The logical network stores real relations between elements and provides a great opportunity to work on modelling of the processes which are connected with the analysis of the risks of flooding.

All operations conducted during the production of the geometric network of sustainable water flows of the territory can be divided into several stages: 1) developing classes of hydrographic objects of the geometric network: linear and point layer rules; 2) developing topology in the ArcGIS: *ArcCatalog / Topology Network*; 3) developing the geometric network in the *ArcCatalog: Geometric Network* from existing classes of spatial objects; 4) setting connectivity rules among the geometric network *Edges* and *Junctions* elements; 4) defining directions of the river flows by using *Geometric Network Editing* and *Utility Network Analyst* toolbars.

The first stage of developing the geometric network included the digitization of the rivers in the linear class of objects (*Hidrography_Stream*.shp*) and in the polygon class of objects (*Hidrography_Lake*.shp*).

The linear class (*Hidrography_Stream*.shp*) defines hydrography data. In order to create an accurate terrain model, this class should contain data on the direction of river streams. The Polygon class of objects (*Hidrography_Lake*.shp*) defines information on the location of water reservoirs: lakes and ponds. This option is necessary for achieving the hydrographic precision in order to build the terrain.

In the process of developing the geometric network of sustainable water streams, the linear class of objects (*Hidrography_Stream*.shp*) has been converted into the point class (*Hidrography_point*.shp*) by using ArcGIS conversion tools: *Polyline to Point*. Each linear class of objects has been assigned with z value (in meters above sea level (m.s.a.l.)), which is based on the terrain data (Earth surface height points, isolines and waterside) obtained from the topographic maps of the University of Latvia map network: *Web Map Server (WMS)*. The linear classes of objects have also been assigned with x and y values (in meters) by using: *Arc Toolbox / Data Management Tools / Features/ Add XY Coordinates* in the GRS 1980 Transverse Mercator coordinate system.

To obtain a "hydrologically accurate" surface model of the research territory received with the help of two different techniques: from the Earth surface height points with a photogrammetric technique (orthophotomaps of dimension 1 : 10 000, LGIA 2005) and from topographic data (topographic maps of dimension 1 : 10 000, created by the General Headquarters of the former USSR in 1963) have been used, manually digitalizing the scanned cartographical materials.

The second stage is developing topology. The procedure applied *Network Topology: ArcCatalog / Feature Dataset / New / Topology*, monitors spatial relations among objects in the dataset.

The third stage carried out the formation of a geometric network from the already existing classes of objects by using a geometric network creation tool. The procedure is applied as

follows: *ArcCatalog / Feature Dataset / Network / New / Geometric Network*.

The development of the network involved point and linear classes of objects, which were created in the first stage. The options of the geometric network building toolbar offer the display of the river start points (outflows) and end points (sinks) in the network within the map frames.

The fourth stage sets up connectivity rules among the (*Edges* and *Junctions*) elements in the geometric network. Elements in a geometric network have been precisely connected to one another. The input elements have been adjusted to ensure connectivity by snapping tolerance – type "1.0".

The editing mode of the last stage sets up the direction of the river streams. The toolbar functions: *Geometric Network Editing* and *Utility Network Analyst* in ArcMap enabled editing and imaging of the directions of the river flows. Every class in the network must have a field that determines whether a feature is enabled or disabled. Enabled and disabled features affect how the flow results are determined. *Edges* and *Junctions* elements feature the classes specified as having an ancillary role. The ancillary role field determines if junction features and elements are sources or sinks.

III. TECHNIQUES OF CREATING ACCURATE DIGITAL TERRAIN MODEL

In order to create the hydrologically accurate models of the surface, it is advised to apply the interpolation algorithm *Topogrid* of the *ArcGIS 3D Analyst* module.

Interpolation is the procedure of predicting the value of attributes (values of height points) at unsampled sites from the measurements made at point locations within the same area or region. The rationale behind the interpolation is that, on average, values of the attribute are more likely to be similar at points which are close together, rather than those further apart. [6].

The given *Topogrid* algorithm of the *Topo to Raster* interpolation tool has been created specifically for the complex use of landscape data (values of height points and isolines), as well as other data on the given territory (such as hydrography, output raster boundary, present holes, hollows, lows).

This method combines the efficiency of multivariate interpolation *Inverse Distance Weighting (IDW)* and surface curve smoothing of the *Spline* method.

IDW is a method of reverse weighed distances which allows calculating values of the function in optional data points and presents a sum of weighed function values at start points. The *Spline* method is a form of interpolation which enables calculating of spline values as an average coefficient of all start points [4].

IDW and *Spline* are two deterministic methods that create surface from samples based on the extent of similarity or degree of smoothing. However, while a *Spline* surface passes

exactly through each sample point, an *IDW* will pass through none of the points [5].

The *Topo to Raster* method imposes constraints that ensure a hydrologically correct digital elevation model that contains a connected drainage structure and correctly represents ridges and streams from the input contour data [5].

It is well – known that the landscape of a territory is the main cause of water erosion, which, in its turn, causes floods. The landscape of the territory determines the direction of water streams and places of accumulation of still surface water. The length and steepness of the slope, the size of the drainage basin, and the form of the slope surface determine the degree of the development of erosive processes, where water is the main erosive power. The *Topogrid* algorithm estimates such landscape features and takes up the area as an interlinked network, which consists of local lows – minimums and elevations – maximums. This principle places limits on the interpolation process, thus saving cohesion of the hydrographic network and accurately mapping the geomorphology and hydrography of the area. The aim of modelling the drain in the *Topogrid* algorithm is also to eliminate unidentified local variations.

The *Topogrid* interpolation technique represents landscape point classes of objects and also polylines classes of objects. The linear class represents landscape isolines and, from the start, represents the most widespread method of producing landscape information. The majority of the interpolation techniques can not apply landscape isolines, besides errors appear, due to lack of information between isolines, and that is unacceptable for flat terrain areas.

In order to produce an accurate digital terrain model of the Laucesa river flood – an endangered area in ArcGIS with the *Topo to Raster* tool, the following input feature data have been used: *Boundary*.shp*, *Hydrography_Pointelevation*.shp*, *Hidrography_Lake*.shp* and *Hidrography_Stream*.shp*.

IV. RESULTS

On the first stage of developing the accurate digital model, the polygon class of objects (*Boundary*.shp*) was created, which contains a single polygon that represents the outer boundary of the output raster. The area of the polygon is 42.59 km².

The second stage of developing the accurate digital model included digitization of the terrain in the linear class of objects (*Topography_Contour*.shp*) by using the map of the University of Latvia map network: *Web Map Server*.

Therefore, on the third stage, the linear classes of objects (*Topography_Contour*.shp*) were converted into point class of (*Topography_Pointelevation*.shp*) using the ArcGIS conversion tools: *Polyline_to_Point*. As a result of conversions, the following data were obtained: 43799 points, *z* min – 85.20 m.s.a.l, *z* max – 131.0 m.s.a.l. With the help of *Arc Toolbox / Data management Tools / Features/ Add X Y Coordinates*, each point class of objects was assigned with *X Y* coordinate value.

For modelling the surface of the terrain, taking into account hydrographic objects, the point class of landscape (*Topography_Pointelevation*.shp*) was supplemented with hydrography point class (*Hidrography_point*.shp*). The result was the formation of the point class of (*Hydrography_Pointelevation *.shp*) containing landscape contours and water levels and consisting of 64055 points, the smallest *z* min – 85.20 m.s.a.l and the largest elevations value *z* max – 131.0 m.s.a.l, out of which the digital terrain model for the flood endangered territory of the Laucesa river was built.

The fourth stage allowed for the development of the accurate digital terrain model by using ArcGIS interpolation by means of *3D Analyst* module: *Raster Interpolation / Topo to Raster*.

The accurate digital terrain model used digitized layers with defined landscape contours, lakes, area boundaries, as well as a geometric network, including the hydrography objects of *Input feature data / Feature Layer – (Boundary*.shp; Hydrography_Pointelevation*.shp; Hidrography_Lake*.shp)* and also the geometric network of sustainable water streams *Feature Dataset / Geometric Network*.

It is essential to note that, within the coastline of water objects of the polygon class (*Hidrography_Lake*.shp*), interpolation was not conducted, due to the fact that outer raster cells inside the lake got the value of the cell heights lying outside along the object coastline. This way, the surface of the water object remains flat, whereas elevations have the same value along the whole surface of the lake.

In the process of *Topo to Raster* interpolation, the following additional interpolation parameters have been considered: 1) the output cell size is 5.0, limited in width or height of the extent of the input point features in the input spatial reference, divided by 250.0; 2) the output extent (*Boundary *.shp*) parameters: left – 643463.93, top – 6199729.03, right – 661056.23 and bottom – 6179743.85; 3) the default margin in cells is 20.0, i.e. the distance between cells to interpolate beyond the specified output extent and boundary; 4) the smallest *z* value to be used in the interpolation is 85.20 m.s.a.l and the largest *z* value to be used in interpolation is 131.0 m.s.a.l.; 5) drainage enforcement is the default – *Enforce*, the algorithm will attempt to remove all sinks it encounters, whether they are real or spurious; 6) the dominant elevation data type of input feature data is SPOT (points); 7) the maximum number of iterations – the default of 40.0 is normally adequate for both contour and line data; 8) the roughness penalty is 0.5; 9) the discrete error factor is 1.0. The discrete error factor is used to adjust the smoothing when converting the input data to a raster; 10) the vertical standard error is zero; 11) the tolerance 1 reflects the accuracy and density of the elevation points in relation to the surface drainage. The tolerance 1 value is zero; 12) the tolerance 2 prevents drainage clearance through unrealistically high barriers. The tolerance 2 value is 200.

The fragment of the *Topogrid* surface of the territory displayed in the geometric network of sustainable water streams *Feature Dataset / WaterNet / Network_Net_Junctions* and *Network_Net_Edges* is provided on Figure 1.

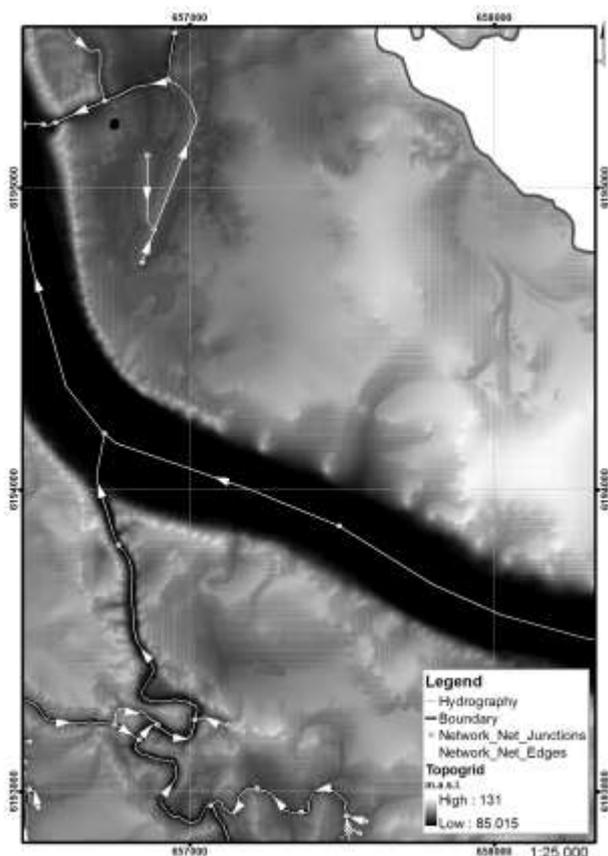


Fig.1. Fragment of the *Topogrid* surface of the flood endangered territory of the Laucesa River. The surface reflects the geometric network of sustainable water streams *Feature Dataset WaterNet / Network_Net_Junctions* and *Network_Net_Edges*.

In order to carry out a comparative analysis, it was necessary to build the Triangulated Irregular Network (*TIN*) by means of the module: *3D Analyst / Create TIN From Features / Hydrography_Pointelevation *.shp / Add / Adges with the same symbol / Add / Node*, tag value grouped with a unique symbol. The triangles have been built through three points with irregular positioning. *TIN* displays the surface through the given points, split and connected in triangles, in other words, by triangulation. Each triangle contains the topologic information on nearby triangles, this way creating a network. Number of Data Nodes: 62560.0. Number of Data Triangles: 125089.0, z range: (85.20, 131.0) m.s.a.l.

The fragment of the Triangulated Irregular Network is provided on Figure 2.

In order to carry out the comparative analysis *TIN*, the surface was converted into *GRID* by means of the *3D Analyst / Convert / TIN to Raster* tool. The results obtained from the *Topogrid* and *Tingrid* surfaces (*Layer properties / Symbology / Classify / Parameter / Value*) are presented in Table 1.

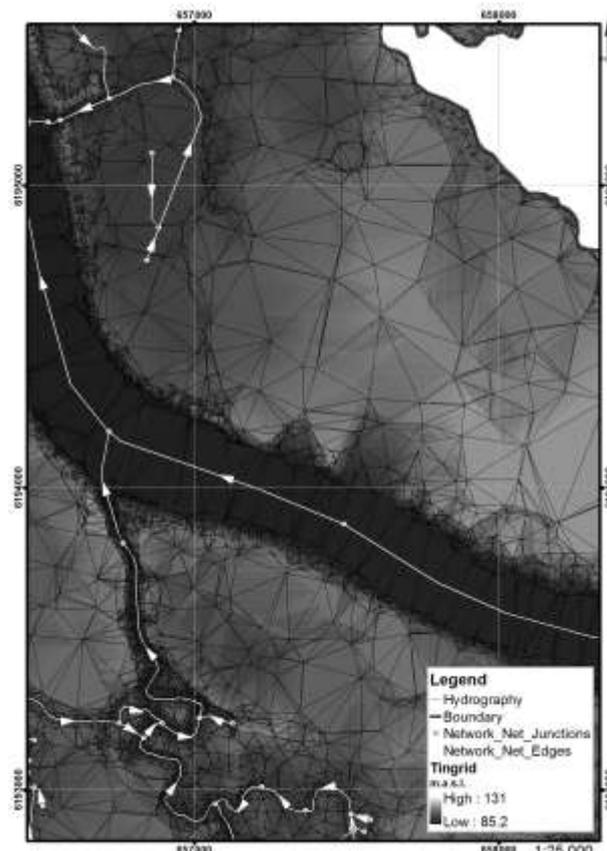


Fig.2. Fragment of the *TIN* surface of the flood endangered territory of the Laucesa River. The surface reflects the geometric network of sustainable water streams *Feature Dataset/ WaterNet / Network_Net_Junctions* and *Network_Net_Edges*.

TABLE 1
SURFACE MODELS PARAMETERS

Parameter	Topogrid	Tingrid
	Value	
Minimum, m	85.20	85.20
Maximum, m	131.0	131.0
Standard deviation	4.97	7.46
Variance, m	69.42	56.65
Skewness	2.22	2.78
Kurtosis	8.68	11.04
Quartile1, m	85.25	91.86
Median, m	92.45	93.0
Quartile3, m	94.80	94.98

The visual analysis of the obtained surfaces *Topogrid* and *Tingrid* in ArcGIS required building of three – dimensional (*3D*) landscape models. The development of the models used *3D Analyst/ ArcScene*, z – the factor is 25.0 (for flat land territories). The results of the *3D* landscape model built on the basis of a *Topogrid* surface are presented on Figure 3.

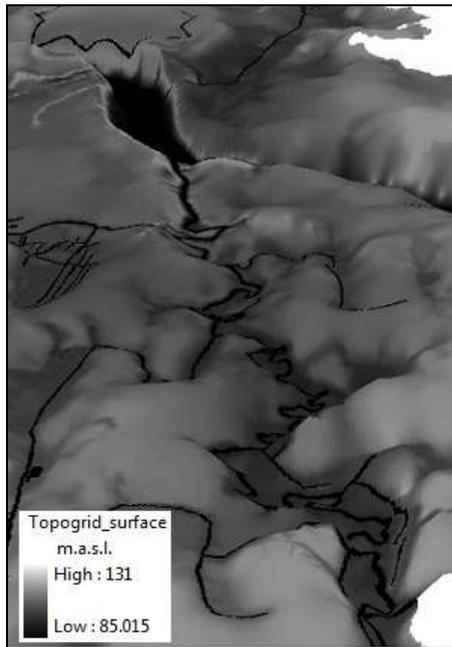


Fig.3. Fragment of the *Topogrid* surface. The results of the 3D landscape model built on the basis of the *Topogrid* surface.

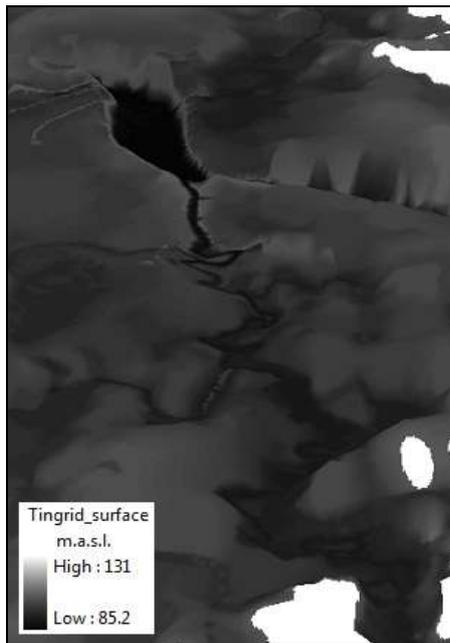


Fig. 4. Fragment of the *Tingrid* surface. The results of the 3D landscape model built on the basis of *Tingrid* surface.

The results of the 3D landscape model built on the basis of a *Tingrid* surface is presented on Figure 4.

The analysis of the obtained data leads to the conclusion that the surfaces built by means of *Topogrid* and *Tingrid* are quite accurate and consider the geometric river network. It is noteworthy that,

despite of high accuracy in terms of visual performance, *TIN* stays behind the technique of raster interpolation *Topo to Raster*.

V. CONCLUSIONS

The result of interpolation in ArcGIS by means of the *Topo to Raster* function was the development of the digital terrain model of the flood endangered territory of the Laucesa River surveying the hydrographic network. From all available interpolation techniques, the most "hydrologically accurate" 3D surface model has been obtained with the *Topo to Raster* technique; its quality considerably exceeds the one of models obtained with other interpolation techniques. This function considered not only the spatial location of landscape isolines, but also location of the river network, closed water reservoirs (lakes) and local lows of landscape. The important feature is the availability of data in the hydrologic layer on the direction of river streams. The ArcGIS environment solves this issue by creating a geometric network of sustainable water streams. Thus, the hydrologic coherence allows applying this model as a basis for further hydrodynamic modelling.

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Olga Kovalova. Upes plūsmas ģeometriskā tīkla izveide.

Rakstā aprakstīta "hidroloģiski korekta" virsmas modeļa iegūšanas metodika *ArcGIS* programmatūras vidē, applūšanas zonas robežu identificēšanai ūdens līmeņa izmaiņu laikā. Šī mērķa sasniegšanai tika izveidots upes plūsmas ģeometriskais tīkls, kura hidrogrāfijas slānis satur datus par upju tecējuma virzienu. Par pētījuma platformu tika izvēlēts interpolācijas metodes *Topo to Raster* modulis *Topogrid*, kuru izstrādāja uz *ANUDEM* programmatūras pamatnes Michaels Hutchinsons 1988. – 1989. gados. Interpolācijas modulis ļauj aprēķināt virsmas modeli, kura kvalitāte daudzkārt pārsniedz parastām interpolācijas metodēm iegūto modeļu rezultātus, jo dotajā metodē jāņem vērā ne tikai zemes virsmas augstumu atzīmes punkti, bet arī upes plūsmas ģeometrisko tīklu. Rezultātā tika iegūts korekts virsmas modelis, kurš paredzēts hidrodinamisko aprēķinu ģeotelpiskajai projicēšanai.