Digital Model of the Turgoyak Lake System, Southern Urals

Chernova I. Yu., Kosareva L.R., Nurgalieva N.G., Chernova O.S.

Kazan Federal UNIVERSITY

Lake Turgoyak is a unique natural feature and one of the region's largest sources of drinking water. Turgoyak is an oligotrophic, open lake located in a narrow intermountain basin, squeezed between the Ural Tau and Ilmensky ranges (Fig. 1). The lake's watershed is quite limited, since it is defined not by large mountains, but by relatively low ridges and chains of individual hills surrounding the lake from all directions. The sediments of lake have been accumulating throughout the Late Pleistocene and the Holocene. Sedimentation is controlled by the lake's morphometry, drainage systems, vertical zoning, thermal state of the water, and wind action.

Therefore, analysis of cartographic materials illustrating the area's geology, topography, drainage systems, watersheds and drainage divides is relevant in this regard. All these aspects are important for assessing the role of sediment sources and transportation routes, as well as deposition mechanisms and sediment distribution within the lake. It should be noted that identification of sources and pathways of pollutants entering the lake is also one of the pressing issues.

Geographic Information Systems (GIS) provide specialized tools for identifying spatial patterns within a set of specified objects. Digital Elevation Models (DEMs) are valuable sources of elevation data, representing the study area as a regular grid, which enables a wide range of morphometric analysis methods to be applied in the study, including slope mapping, drainage and runoff modeling, identifying terrace inflection points, etc.

This study presents a digital model of Lake Turgoyak and its surroundings. The model was developed using GIS software, incorporating available geological, topographical, and bathymetric maps. The resulting model will serve as a foundation for various further studies of Lake Turgoyak, including identification of the lithogenetic features of bottom sediments related to the morphometry of the lake, the relationship between its littoral and pelagic zones, epilimnion and hypolimnion, as well as connected with the structure of ultimate sediment source areas and the composition of the lake's surroundings, represented by metasedimentary formations.

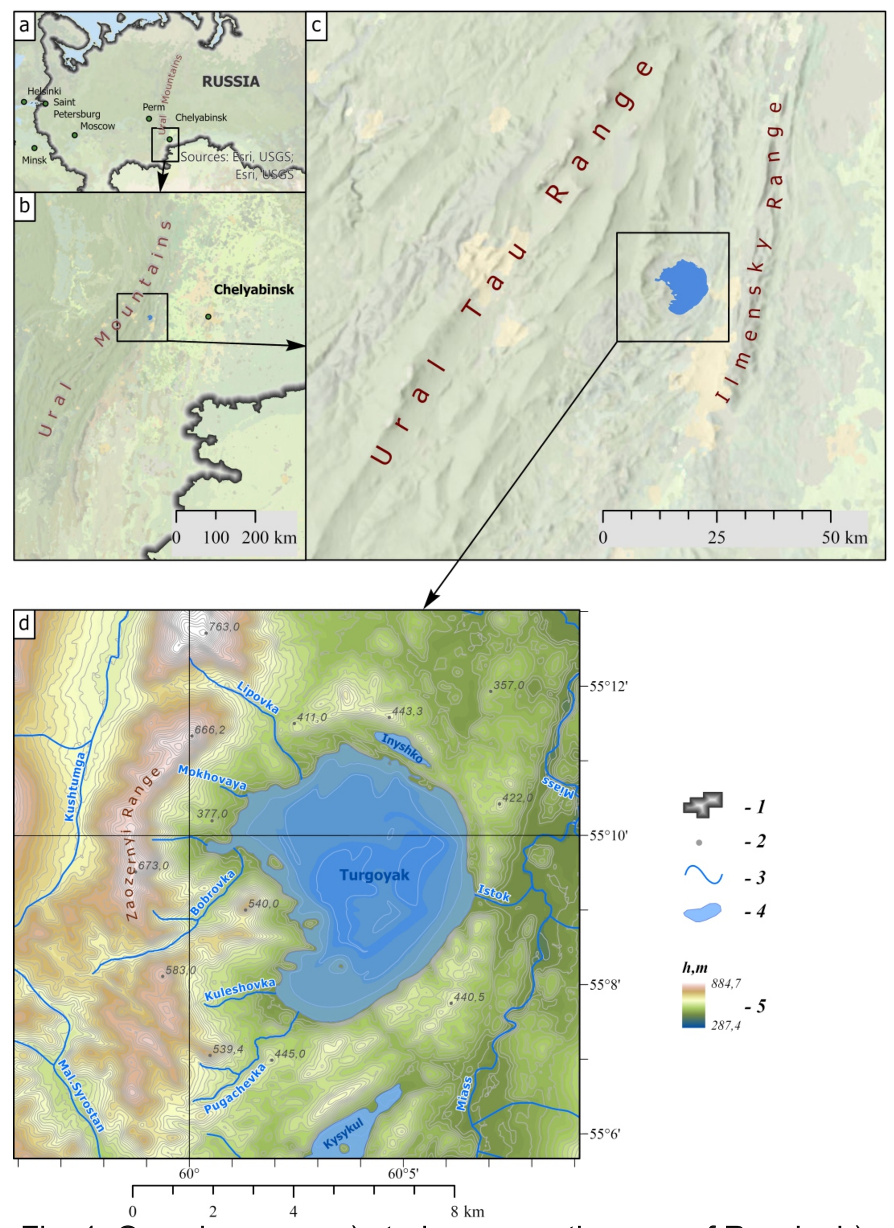

Fig. 1. Overview map: a) study area on the map of Russia; b) Southern Urals region; c) location of Lake Turgoyak in an intermountain basin; d) topography and hydrography of the study area. 1 – border of Russia, 2 - elevation points, 3 - rivers, 4 - lakes, 5 - DEM.

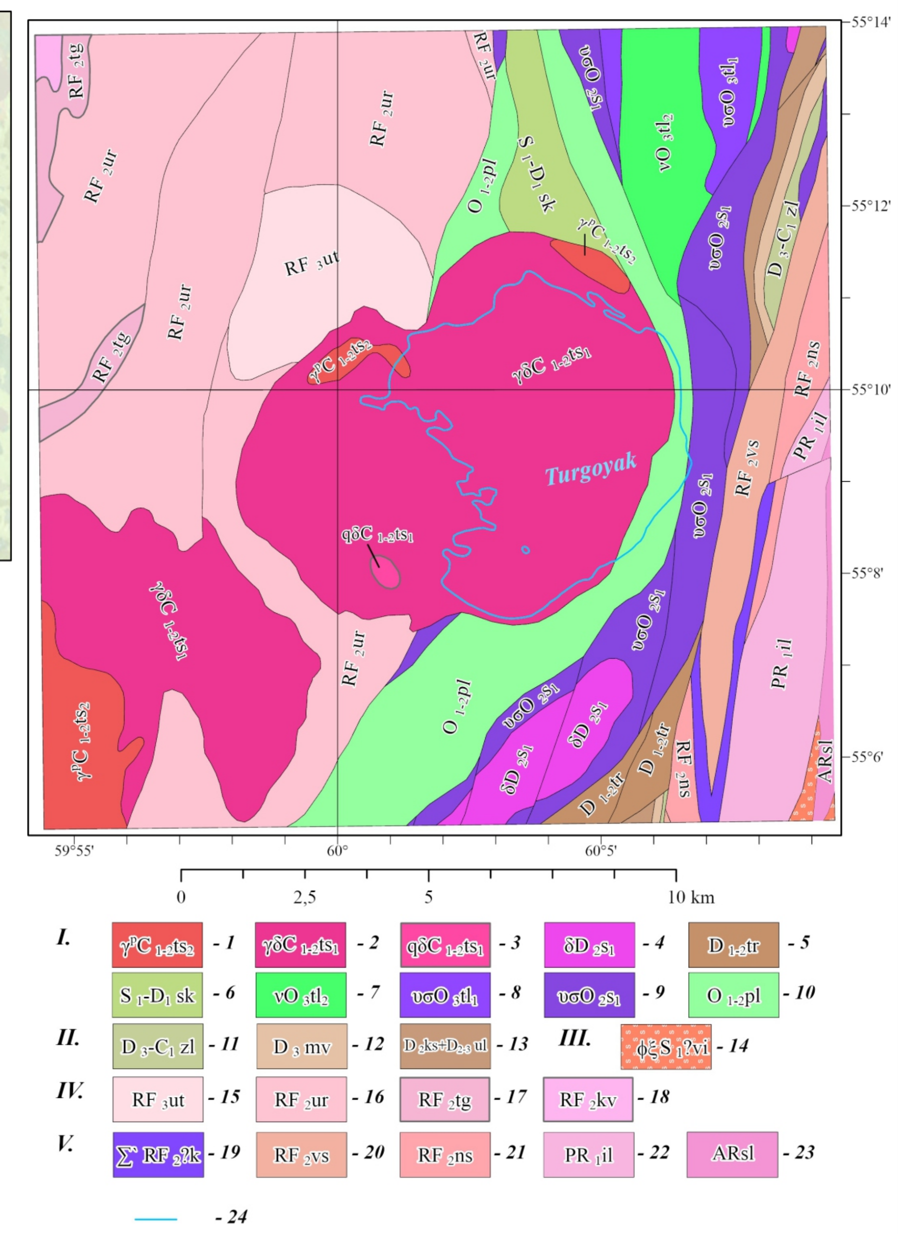

Fig. 2. Digital geological map of the study area, compiled based on the State Geological Map of the Russian Federation at a scale of 1:200,000, sheets N-41-VII and N-40-XII (Petrov et al. 2003; Aulov et al. 2015).

I. Voznesensko-Prisakmarskaya structural zone; II. Zapadnomagnitogorskaya structural zone; III. Sysertsko-Ilmenogorskaya structural zone; IV. Central Ural megazone, Zlatoustovskaya structural zone; V - East Ural megazone, Ilmenogorskaya structural zone. 24 - outline of the current shoreline of Lake Turgoyak.

The digital elevation model shown in Fig.1d was created using all available topographic information sources, and the bathymetry data for Lake Turgoyak [1, 2]. This DEM encompasses both the land surface and the lake bottom topography. The primary data source for the model was the Copernicus DEM GLO-30, provided by the European Space Agency. Data preprocessing, hydrological modeling, and map layout creation were carried out in ArcGIS Pro 3.0.2, featuring the Spatial Analyst extension [3].

To identify the composition of sediment carried into the lake, layers from the digital State Geological Map of the Russian Federation (scale 1:200000, sheets N-41-VII and N-40-XII) were incorporated into the GIS project [4, 5]. The geological maps are provided by Russian Geological Research Institute VSEGEI [6] upon user request. The digital geological map/model of the study area is presented in Fig. 2.

Since the Copernicus DEM is a surface model rather than a terrain model, several processing and refinement steps were necessary, including removing heights associated with man-made structures, smoothing the surface, and eliminating roughness caused by vegetation, small objects, satellite data processing artifacts, and other factors (Fig. 3).

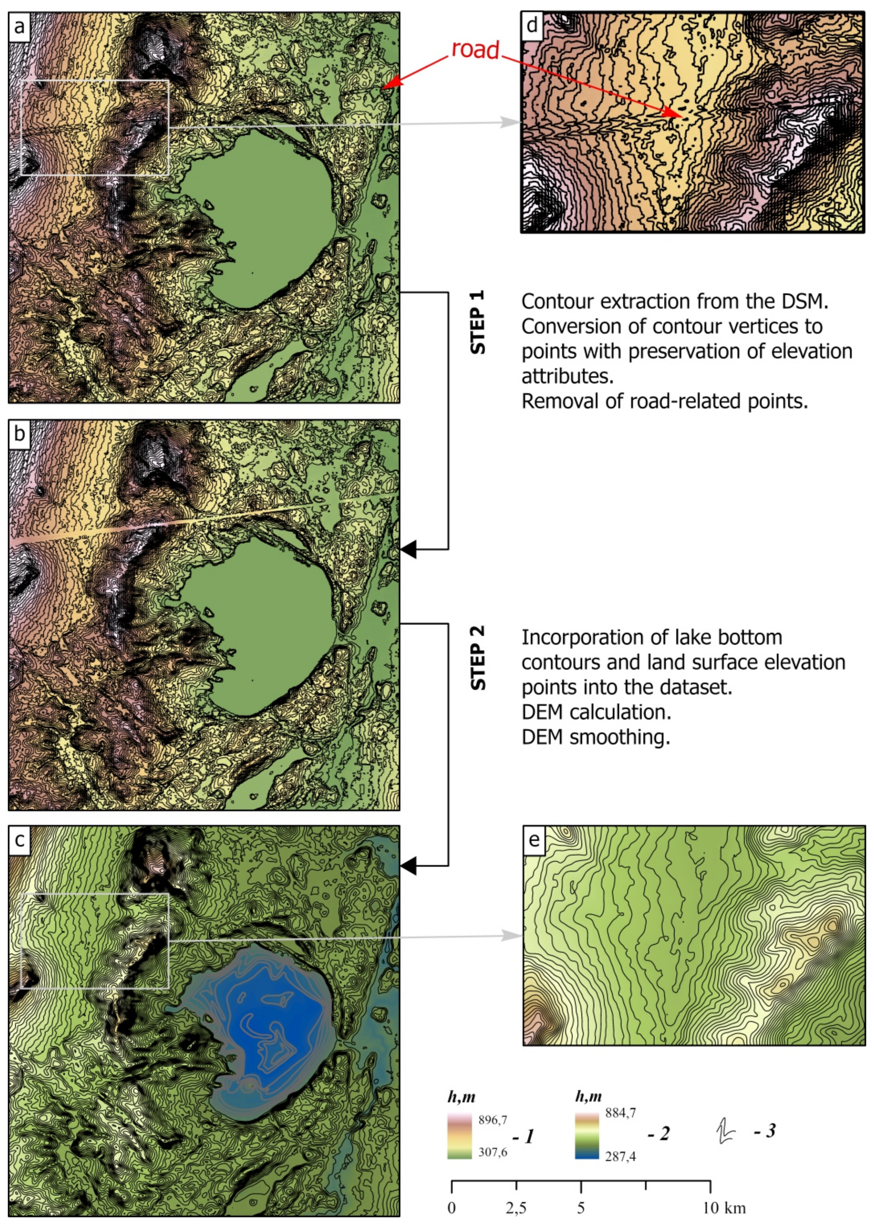

Fig. 3. DEM calculation stages: a) DSM with elevation contours; b) DSM with elevation contours after removal of road-related segments; c) smoothed digital elevation model, including the lake basin topography; d) part of figure a; e) part of figure c. Insets d and e show the same area. 1 - Copernicus DEM (DSM), 2 - smoothed digital elevation model, 3 - elevation contours.

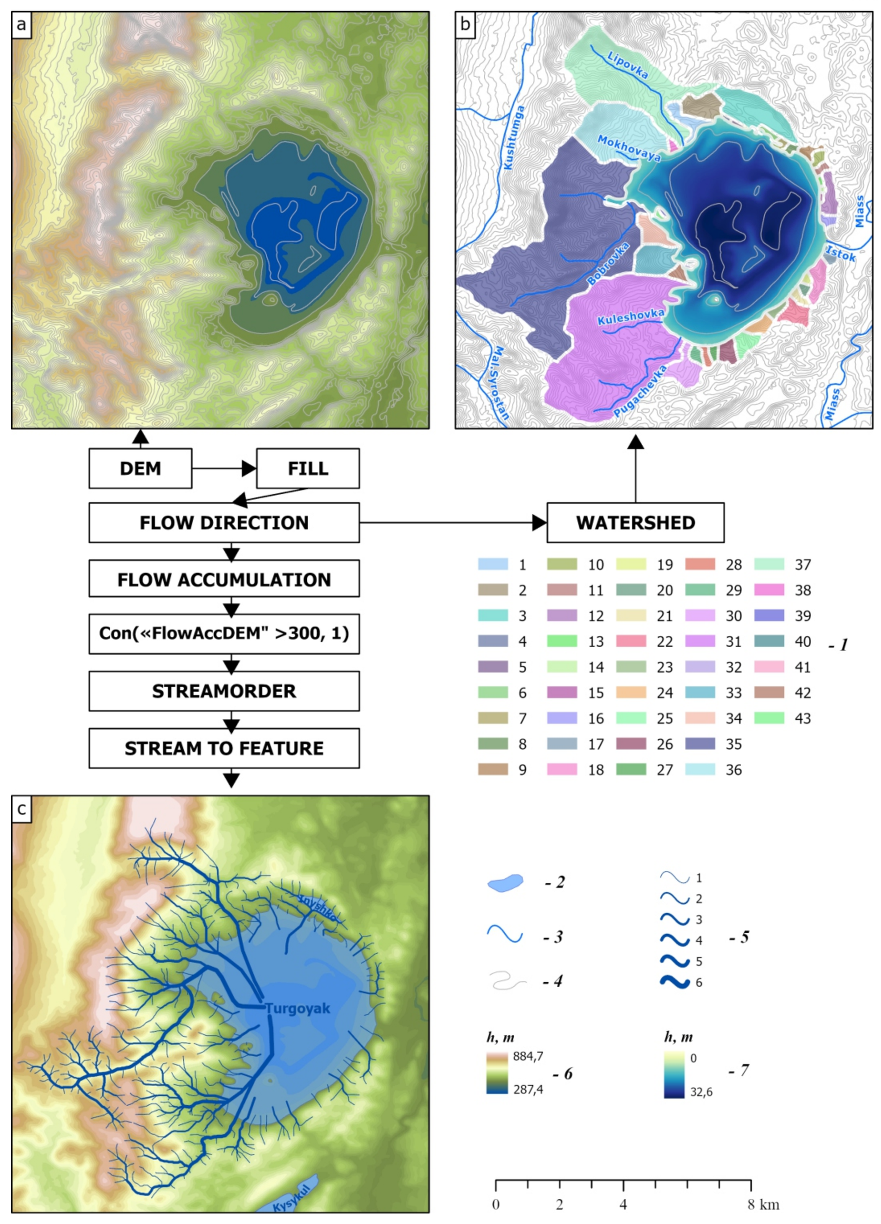

Fig. 4. Hydrological modeling results: a) DEM; b) watersheds; c) drainage networks. 1 - watersheds, 2 - lakes, 3 - rivers, 4 - elevation contours, 5 - stream orders, 6 - DEM, 7 – depth of Lake Turgoyak.

Modeling of watersheds and drainage divides was conducted using the Hydrology toolset in ArcGIS Pro 3.0.2's Spatial Analyst module. Fig. 4 presents the results of hydrological modeling. The application of FILL and FLOW DIRECTION tools eliminated minor DEM artifacts that would have hindered drainage network extraction (Fig. 4a). Watersheds are shown in Fig. 4b. Figure 4c displays the final modeling result, obtained through the use of FLOW ACCUMULATION, CON, STREAMORDER, and STREAM TO FEATURE tools.

Fig. 5 presents another morphometric parameter – the DEM slope. Slope directly influences the intensity of both linear and sheet erosion, therefore determining the intensity of suspended sediment runoff. All other conditions being equal, velocity of flow and changes in its carrying capacity depend on the base level of erosion and slope shape. Erosive forces reach their maximum with steep slopes and a low base level of erosion. Fig. 6 shows the integrated geological/hydrological model of the Turgoyak lake system.

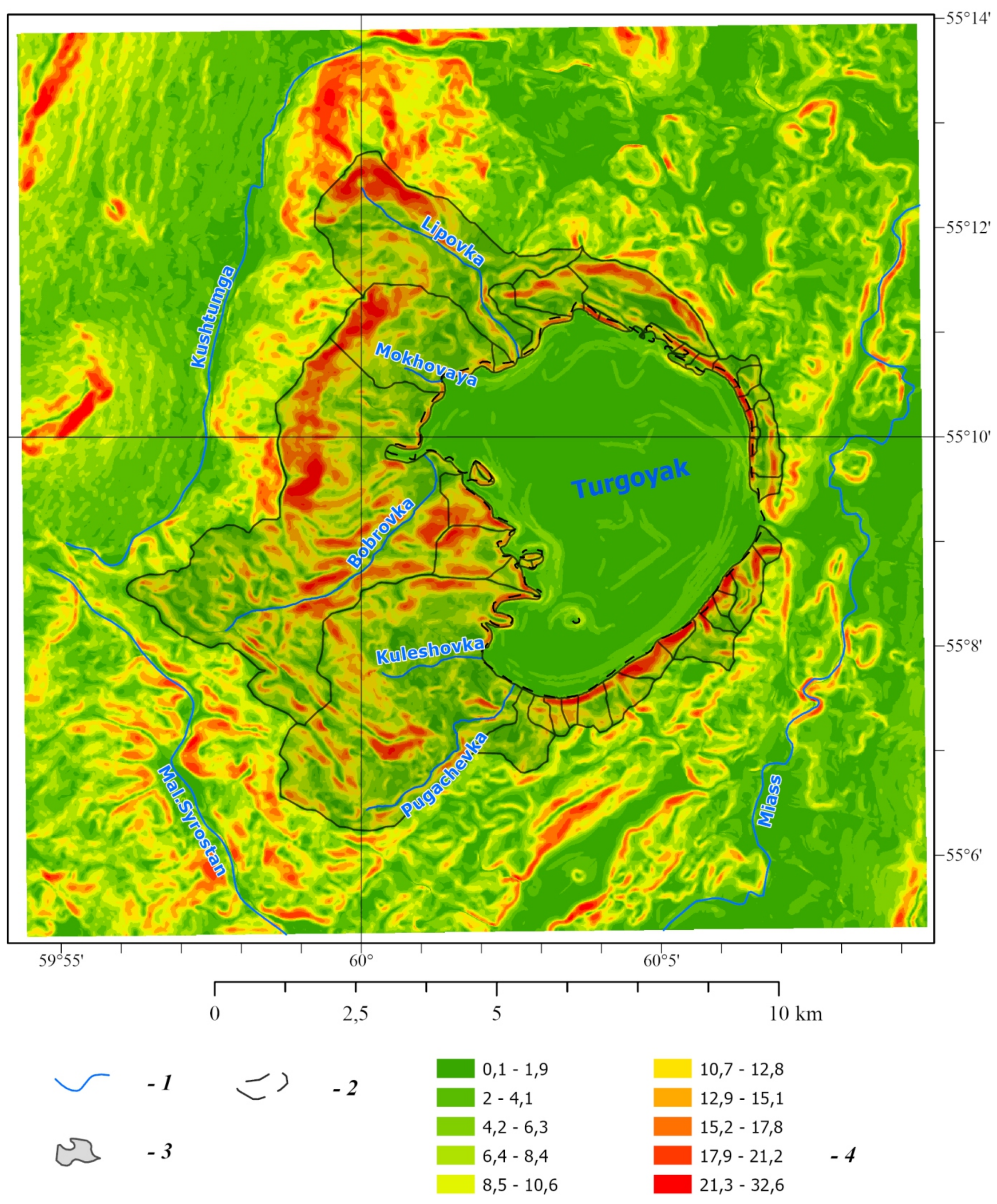

Fig. 5. DEM slope. 1 - rivers, 2 – outline of Lake Turgoyak, 3 - watersheds, 4 - surface slope in degrees.

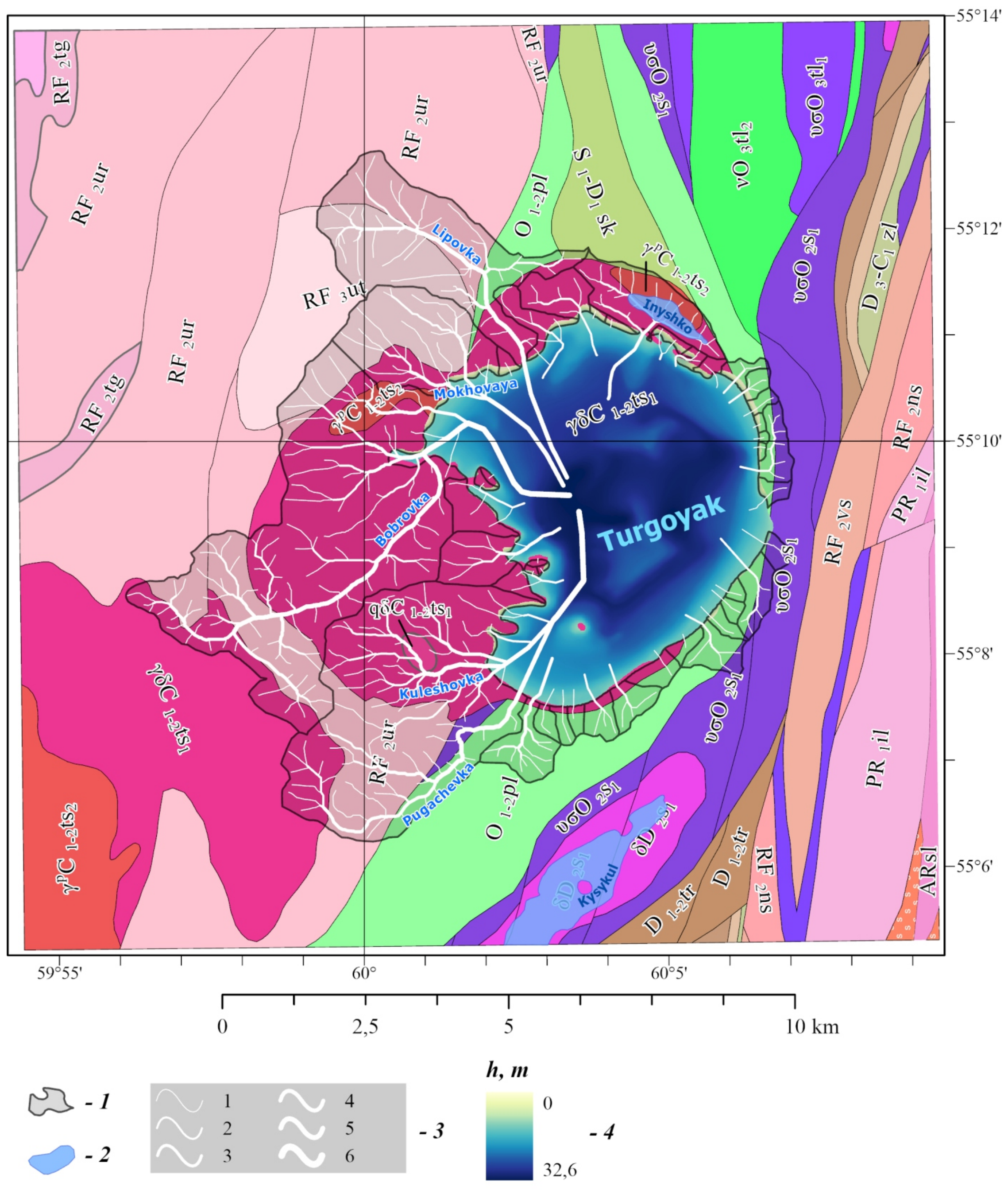

Fig. 6. Integrated geological/hydrological model of the Turgoyak lake system. 1 - watersheds, 2 - lakes, 3 - streams and their orders, 4 - lake depth.

For example, the newly developed digital model highlights the lake's pelagic zone, defined by western and eastern depressions. The pelagic zone borders the littoral zone, which is least developed in the eastern part of the lake. The largest watershed, measuring 17.4 km^2, belongs to the Bobrovka River basin on the western side of the lake. Of this area, 11.85 km^2 is characterized by rocks from the Turgoyakskiy granitoid massif (γδC1–2ts1), while 4.43 km^2 features crystalline schist interlayered with carbonaceous formations and marble from the Urenginskaya suite (RF2ur). An area of 0.76 km^2 is represented by two-feldspar granite with predominant plagioclase from the Turgoyaksko-Syrostanskiy diorite-granodiorite-granite complex (γρC1–2ts2). The western side also includes 8 additional watershed areas totaling 2.08 km^2 and featuring rocks from the Turgoyakskiy granitoid massif (γδC1–2ts1). It's also worth mentioning that the steepest slopes, up to 33°, can be found in the area where the Turgoyakskiy pluton rocks are present, and to a much lesser extent in the area of the Urengnskaya suit crystalline schists. This zone is likely the main source of quartz, feldspar, and carbonaceous material deposited in the lake.

According to the model, the maximum elevation in the area is 884.7 m, which aligns with topographic maps when accounting for the Copernicus DEM's margin of error. The lowest point in the model is located at 287.4 m, which corresponds to the lake's maximum depth of 32.6 m.

The hydrological modeling showed that Lake Turgoyak's total watershed area spans 52.5 km2 and comprises 43 sub-areas. Four of them are large ones – those of the rivers Lipovka, Mokhovaya, Bobrovka, Kuleshovka, and Pugachyovka. In total, they account for 81% of the entire watershed area, primarily framing the lake's northwest, west, and southwest shores. Overlaying the model of the watershed on the geological map allowed for determining the composition of sediments carried into the lake.

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