Channel regulation of Torna stream to improve environmental conditions in the vicinity of red sludge reservoirs at Ajka, Hungary[1]

Introduction

The only alumina factory in Hungary (MAL Ltd.) operates in the neighbourhood of Ajka town, in the western part of the country. A chain of large reservoirs of caustic red sludge (by-product of the Bayer alumina production process) is to be found in the valley of Torna stream.

On October 4, 2010 in the north-western corner of reservoir cassett No. 10 the dam ruptured and ca. 700,000 cubic meters of watered (alkaline) red sludge flooded the low-lying parts of the settlements Kolontár, Devecser and Somlóvásárhely *(Figure 1)* taking toll of human lives and injuries plus causing considerable material damage. Contamination soon reached water courses Marcal, Rába, and later the Danube River *(Photo 1).*

The spill has become known all over the world and once again turned the public attention to disastrous events, both natural and man-induced, to the involvement of different components of geographical environment in these catastrophes and called for the responsible behaviour to take preventive measures that would grant safe operation of large industrial projects and infrastructure.

Topography, geological, soil and hydrogeological conditions of the area affected by the disaster and its wider surroundings show a variable, mosaic-like picture. These conditions are not prone to regulation. However, surface waters as one of the most important natural components can be regulated. A ma-

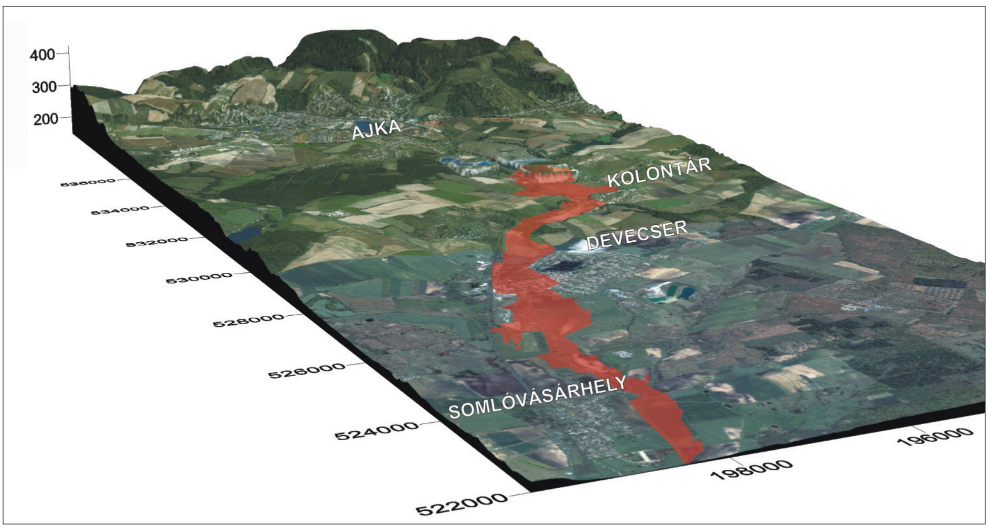

Fig. 1. A perspective satellite image superimposed on the relief model of the area affected by the red sludge flood (from north-western aspect) (compiled by Varga, Gy. 2010)

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Photo 1. Damaged dam of cassett No. 10 and areas affected by the red sludge flood. (Photo by H. Szabó, S. MTI)

jor objective of interventions related to water management is the regulation of the quantity and dynamics of water resources depending on the geomorphological endowments.

Torna stream and its tributaries are important landscape forming factors in the environs of Ajka and Devecser. Regulation of their channel – with a special reference to relocation within the catchment – is promising as for the improvement of the state of environment and physical planning of the area including surface and subsurface waters and red sludge reservoirs.

The methods applied for the elimination of environmental damage and the process of landscape rehabilitation are to attract constant attention of public opinion. Once have been completed, the measures taken will positively affect the security of local population and the quality of environment. No irreversible changes are expected with the relocation of the streambed section, after rehabilitation the initial channel might be used again.

In the research activities of the Geographical Research Institute of Hungarian Academy of Sciences it is a well-proven practice that different factors of the geographical environment (topography, hydrography, soils etc.) are displayed in thematic maps and the result of evaluation is also depicted in synthetic maps.

Environmental survey and mapping from the engineering aspect is a special branch of preliminary studies for large industrial establishments and projects of linear infrastructure (roads, railways) in the phase of technical planning to make a complex plan of construction perfect. Large projects of the past decades are warnings about this (Komló, Miskolc, Kazincbarcika, Salgótarján, Dunaújváros, Oroszlány; certain motorway sections; mass movements along high bluffs with adverse impact on settlements; problems related to deposition of radioactive waste; Gabčíkovo (Bős)–Nagymaros hydrocascade; flood prevention; Paks Nuclear Power Plant; and domestic red sludge reservoirs (Ajka, Mosonmagyaróvár, Almásfüzitő and Neszmély (Balogh, J., Lovász, Gy. 1988; Balogh, J. *et al.* 1988; Schweitzer, F. 1996; Juhász, Á. 2003; Viczián, I. 2003, 2006).

The present study was not aimed at presentation of the red sludge reservoirs and of their complex environmental impact assessment. (They are to be published in a special volume of studies.) One can find below a proposal for the regulation of Torna streambed following a brief introduction in geomorphological features in the environs of the reservoirs. Our propositions are raised for the sake of the improvement of the quality of surface and subsurface waters, and the safe operation of reservoirs.

Geographical environment, hydrographic conditions

The area with the grimmest aftermath of the disaster extending to the settlements Ajka, Kolontár, Devecser, Somlóvásárhely belongs to natural microregions North Bakony and Marcal basin. According to the landscape geographical subdivision the contact zone between these two units is part of Ajka basin on the western margin of Bakony including Veszprém–Devecser trench and at the southeastern end of Pápa–Devecser flat belonging to Little Hungarian Plain (Kisalföld). The boundary between them can be drawn at Devecser.

The studied area is of transitional character; its geomorphological aspect is formed by series of Mesozoic horsts, foothills of the mountain rim dissected by erosional valleys and alluvial fans of the margin *(Figure 2).*

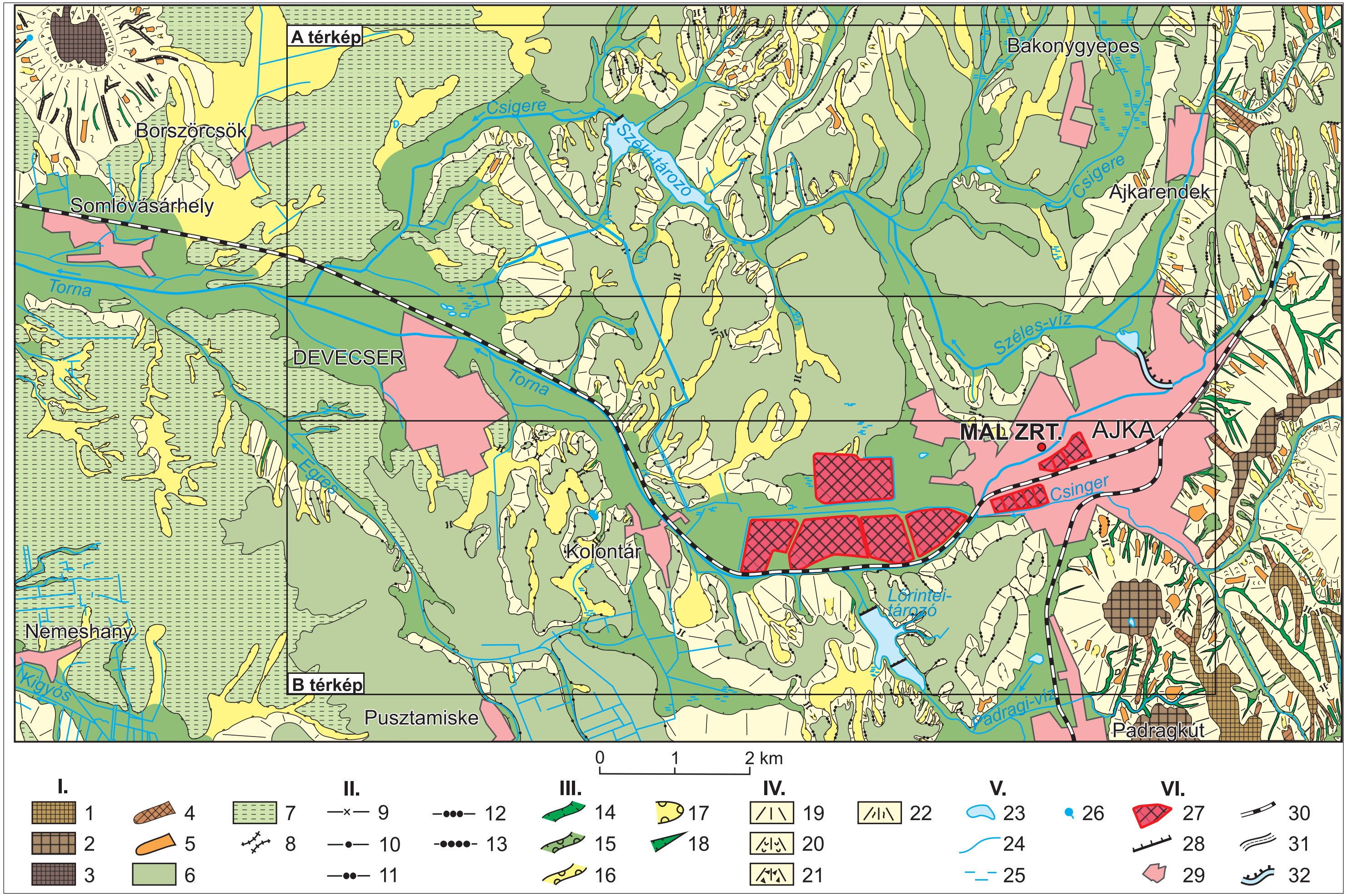
Along the axis of Veszprém–Devecser trench it is Torna stream that drains the waters infiltrating from karstic rocks of Bakony mountains into Pannonian sandy and gravelly foothill sediments and collects surface runoff *(Figure 3).* Torna stream springs in North Bakony at Csehbánya and flows into Marcal river. Within the studied area it receives Csigere stream and Széles stream from the right side whereas Csinger stream and Padragi stream are its left-hand tributaries. Besides, minor water courses and subsurface waters also empty in it. There rise springs in the erosional and derasional valleys dissecting the extensive alluvial cone built by the stream.

In the course of valley direction analysis a definite correlation has been established between the length of the route covered by Torna stream and the dimension of the alluvial fan formed in the mountain foreland. Accordingly, the 51 km long water course with a catchment of 498 km^2 could form an extensive alluvial cone with a fan-shaped widening in a west–southwest direction of Ajka. Torna has been building its alluvium and changing its streambed configuration continuously. The apex of the cone filling in Veszprém–Devecser trench could be immediately west of today's Ajka. The channel was wandering in northwest–southeast direction. Drainage network variations and changes in streambed position can be attributed to subsidence processes of unknown intensity in the western foreland of the Bakony mountains.

The erosional, erosional-derasional and derasional valleys of north-northwest – south-southwest orientation and the divides between them indicate the position of streambeds at the end of Pleistocene and their changes that several geomorphological levels could be associated with. In the immediate surroundings of Ajka the position of valleys refers a fan-like fluctuation of the paleo-Torna stream in the present valleys of Széles stream and Csigere stream from northwest and west to southwest up to Kígyós stream.

In the survey of the recent variations in the stream channel, archive maps and sheets of military surveys were involved as well. A map of the 2nd military survey from 1852 provides a spectacular image of lower lying portions of the alluvial fan with the incising valleys. Such a depression can be viewed north of Ajka *(Figure 4)* being nowadays erosional base of Széles stream and Csigere stream. This area is separated from the current valley of Torna stream merely by a narrow strip of alluvial sediments of some metres elevation.

The formation of the alluvial cone and characteristic geomorphological levels and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AJKA
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features show the following configuration. The valley section between Somlóvásárhely and Ajka is situated between 170 and 350 m a.s.l. and can be subdivided into three parts geomorphically. The uppermost are the summit levels (300–350 m), lower there are foothills dissected by valleys. Within the latter an intermediary level of alluvial cones (220–300 m) and a low level of alluvial fans (170–220 m) along the mountain rim are to be distinguished. The difference between the relief energy of alluvial cones of low and intermediary position is the result of the sediment transport by and channel variation of Torna stream.

Summit levels of 300–350 m a.s.l. are composed of horsts and Mesozoic limestone formations. These areas are located east of the town, whereas their western boundary is the streambed of Torna (northeast of the town) and the southern one is the valley stretching in the direction of Padragkút. The steep (25–35%) slopes are built of Pannonian clay. Such geological and landform conditions have played a key role in the formation of extensive slopes with landslide hazard along Csigere stream.

By both banks of Torna stream there are foothill surfaces strongly dissected by erosional and erosional-derasional valleys. The area below 300 m a.s.l. can be subdivided into alluvial cones, geomorphological levels. Intermediary surfaces between 220–300 m bear imprint of landform evolution under the impact of Torna stream during Pleistocene and at the end of that epoch. Lower surfaces (170–220 m) show traces of the activity of the water course related to channel fluctuations and sediment redeposition at the end of Pleistocene and during Holocene. In the talweg of Torna marshy and swampy places emerged.

An option for the channel regulation of Torna stream and diversion of its flow

Ajka town with its industrial estates and the red sludge reservoir is to be found in the valley of Torna stream with a width alternating between 1 and 3 km. Above Ajka i.e. in its middle mountain section the watercourse is natural water, but downstream it became regulated. In the course of urbanization the town has expanded from the higher geomorphological levels toward the alluvial plain. Red sludge reservoirs also were established in Torna valley *(see Figure 3).* The natural valley of the stream was found initially in the place where cassettes No 8., 9. and 10. are placed at present, and it became diverted when the reservoir was under extension during the 1990s. Observing wells operating in monitoring system provide continuous information about subsurface water flow and quality is also checked by Middle Transdanubian Environmental and Water Management Directorate permanently *(Photos 2* and *3).*

The above water course regulations have not brought about adequate changes in protection of water quality. An appropriate solu-

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Fig. 2. Geomorphological map of the wider surroundings of red sludge reservoirs at Ajka (compiled by Balogh, J., Lovász, Gy., Schweitzer, F. 2010). – I. Complex landforms: 1 = summit level 300–350 m a.s.l.; 2 = summit level > 350 m a.s.l.; 3 = summit level of residual basalt hill; 4 = interfluvial ridge; 5 = gentle slope segment; 6 = glacial alluvial cone in intermediary position; 7 = glacial alluvial cone in low position; 8 = saddle; II. Geomorphological levels; 9 = 170–180 m a.s.l.; 10 = 180–220 m a.s.l.; 11 = 220–240 m a.s.l.; 12 = 240–270 m a.s.l.; 13 = >270 m a.s.l.; III. Valleys; 14 = erosional valley; 15 = erosional-derasional valley; 16 = derasional valley; 17 = derasional niche; 18 = ravine, canyon; IV. Slopes; 19 = slopes undistinguished; 20 = slopes with landslide hazard; 21 = steep slope of rock and debris (>35%); 22 = slopes with gully erosion hazard; V. Waters; 23 = lake; 24 = stream, drainage canal; 25 = waterlogged area; 26 = spring; VI. Man-made landforms; 27 = cassettes of red sludge reservoir; 28 = valley dam; 29 = builtup area; 30 = railway; 31 = dirt road cut in loess; 32 = projected hydraulic structure with a possible new channel of Torna stream after diversion

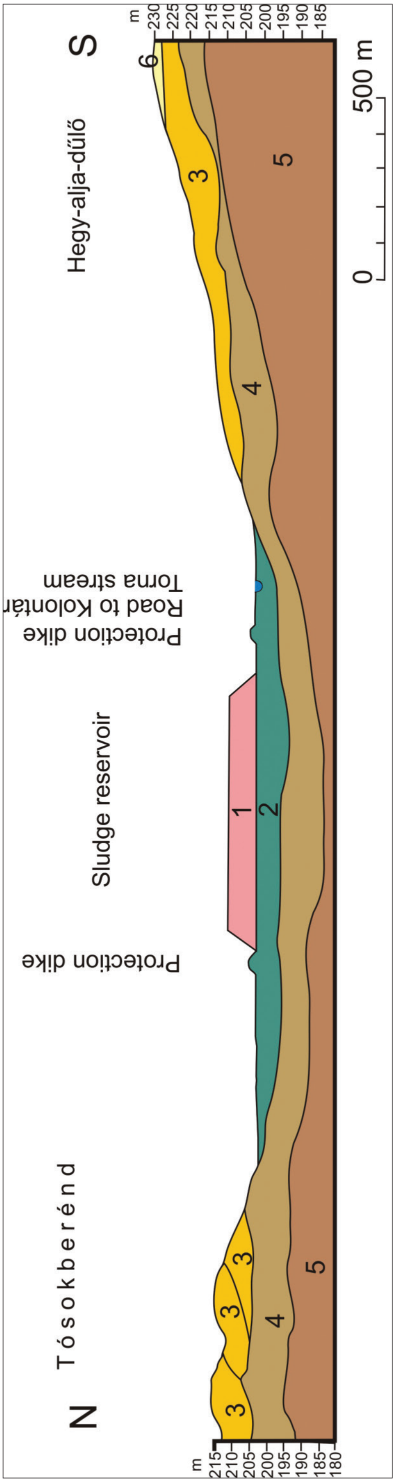

Fig. 3. Spoil heaps and sludge reservoirs upon the alluvium of Torma stream between Ajka and Tósokberénd (ed. by Juhász, Á. 2003). – 1 = sludge reservoir, spoil heap; 2 = alluvial sequence (sand, gravel, silt); 3 = terrace built of alluvium (gravel, sand) of the ancient streams (Torna, Csigere); 4 = Somló Formation (Pannonian sand, clay); 5 = Csatka Pebble Formation; 6 = slope loess, sandy loess (clastic gravel sequences)

Photo 2. Observing wells monitoring water quality along the dam of red sludge reservoir (Photo by Juhász, Á. 2003)

Photo 3. Foamy alkaline water flowing out of leakage of sludge reservoir (Photo by Juhász, Á. 2003)

Photo 4. Waste water contaminated by red sludge in the drainage ditch flanking the reservoirs (Photo by Juhász, Á. 2003)

Fig. 4. A wider surroundings of Ajka on the map of the 2nd Military Survey (1852) prior to the construction of sludge reservoirs (above), topographic map of the area in 2010 (below). Red sludge cassettes are marked with red contour lines

tion for the problem of surface and subsurface waters and especially for the safety operation of sludge reservoirs can be provided by taking a large scale but not too expensive water management measure. In accord with the paleogeographic conditions the following proposal is made.

North of Ajka town, in the valleys of Széles stream and Csigere streams (that used to form the channel of Torna stream at the end of Pleistocene) present-day discharge of the latter could be drained with relocation of a short section of the stream bed. Planning of the channel to be newly shaped requires thorough geomorphological survey as the channel is to be cut within the administrative area of the town *(Figures 5* and *6).*

The water of Torna stream to be diverted into Széles stream and then proceeding in the streambed of Csigere could improve the quality of water in Széki reservoir, add to the capacities of storage and carry away flash floods caused by extreme precipitation events. Water of streams Torna and Csigere flowing together would return to its channel between Somlóvásárhely and Devecser.

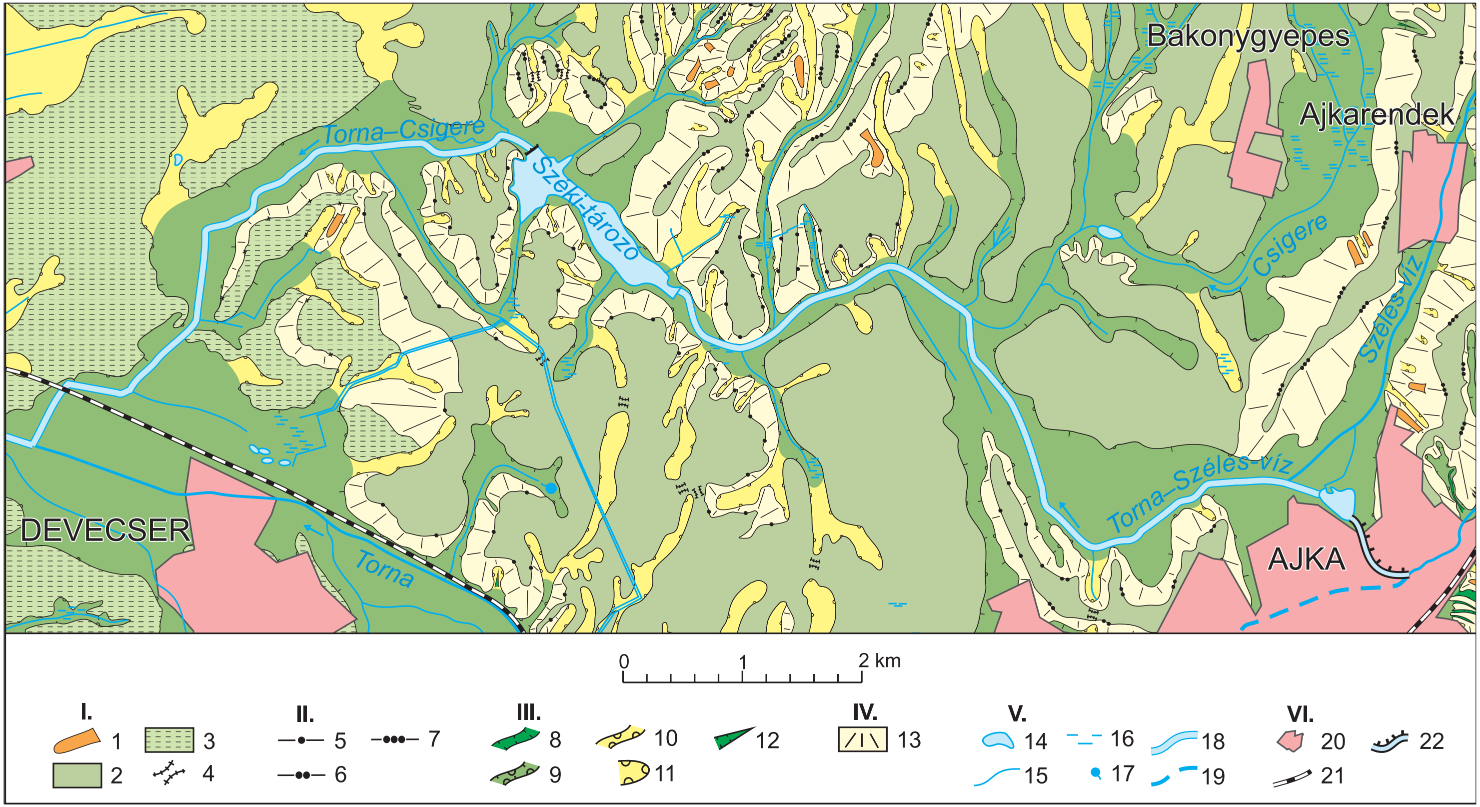

Fig. 5. State subsequent to the projected flow diversion, *map A* (compiled by Schweitzer, F. 2010). – I. Complex landforms: 1= gentle slope segment; 2 = glacial alluvial cone in intermediary position; 3 = glacial alluvial cone in low position; 4 = saddle; II. Geomorphological levels; 5 = 180–220 m a.s.l.; 6 = 220–240 m a.s.l.; 7= 240–270 m a.s.l.; III. Valleys; 8 =erosional valley; 9 = erosional-derasional valley; 10 = derasional valley; 11 = derasional niche; 12 = ravine, canyon; IV. Slopes; 13 = slopes undistinguished; V. Waters; 14 = lake; 15 = stream, drainage canal; 16 = waterlogged area; 17 = spring; 18 = a possible solution of water diversion; 19 = desiccated channel of Torna stream; VI. Man-made landforms; 20 = built-up area; 21= railway; 22 = projected hydraulic structure with a possible new channel of Torna stream after diversion

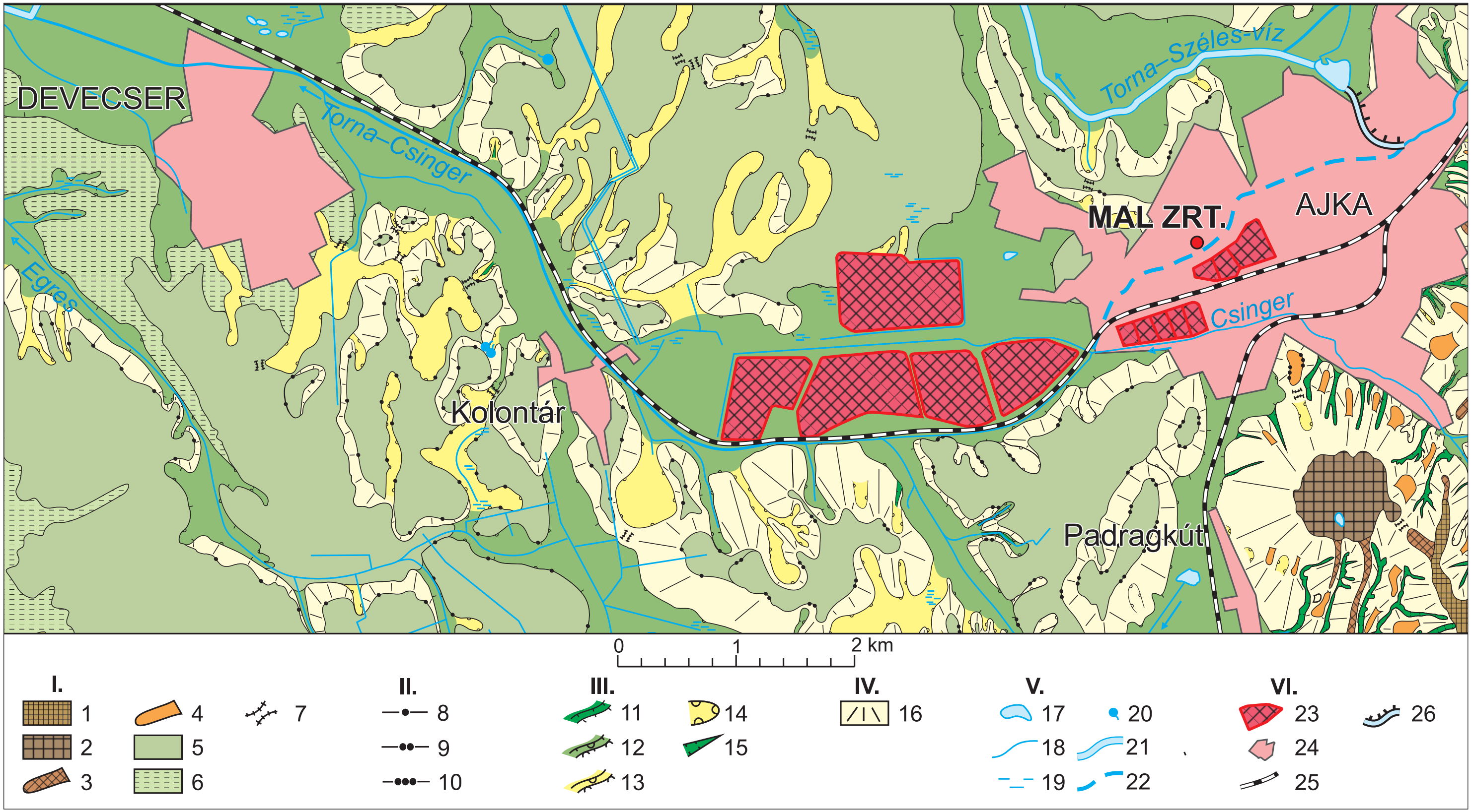

Fig. 6. State subsequent to the projected fl ow diversion, *map B* (compiled by SCHWEITZER, F. 2010). – I. Complex landforms: 1= summit level >350 m a.s.l.; 2 = summit level 300–350 m a.s.l.; 3 = interfl uvial ridge; 4 = gentle slope segment; 5 = glacial alluvial cone in intermediary position; 6 = glacial alluvial cone in low position; 7 = saddle; II. Geomorphological levels; 8 = 180–220 m a.s.l.; 9 = 220–240 m a.s.l.; 10 = 240–270 m a.s.l. III. Valleys; 11 = erosional valley; 12 = erosional-derasional valley; 13 = derasional valley; 14 = derasional niche; 15 = ravine, canyon; IV. Slopes; 16 = slopes undistinguished; V. Waters; 17 = lake; 18 = stream, drainage canal; 19 = waterlogged area; 20 = spring; 21 = a possible solution of water diversion; 22= desiccated channel of Torna stream; VI. Man-made landforms; 23 = cassettes of red sludge reservoir; 24 = valley dam; 25 = built-up area; 26 = railway; 27 = projected hydraulic structure with a possible new channel of Torna stream after diversion

The present section of Torna stream now in the immediate vicinity of red sludge reservoir would be eliminated, this way improving the hydrological conditions decisive for the safety of reservoirs. It would provide the opportunity for a safe reparation and reinstallation of all cassettes. A further advantage of diverting the streamflow is that contaminated wastewaters arriving from the alumina factory and sludge reservoir could be collected in the abandoned channel and water cleaned with an adequate treatment.

Besides the improvement of the state of the environment in the area enclosing the red sludge reservoirs the objectives of channel regulation include carrying off water, ice and bed load, securing water uses, flood prevention, water distribution, protection of the existing habitats and creation of new ones and their harmonization with the landscape and specific local requirements raised during water regulation.

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