THE CATCHMENT AREA OF THE AGGTELEK BARADLA CAVE

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The demarcation of catchment areas of surface streams is relatively easy to define. There are time honoured methods to be applied. In most cases surface features indicate the border especially when dividing ridges are well marked or bedrock is impermeable.

This task is not so easy when streams are partly fed by infiltrating water from permeable rocks or either diverging or bifurcating streams belong to the investigated area. Still there are proper engineering methods for such cases.

The problem is much more complicated in the case of subsurface karst-hydrological systems. The cavities of karst springs or karst streams situated below the surface are difficult to access. They are very often hidden and the area which is easy to be surveyed by cartograhical methods is only a small part of the karst outcrop. The usage of fluorescent dye tracers takes a long time, is very expensive, is not always effective and might cause environmental problems. The determination of subsurface water systems is further impeded when one karstwater reservoir supplies more individual subsurface streams. Without knowing the borders of karstwater systems, estimation of karstwater supply, circulation and the effect of human impact would be uncertain. Recently the study of human impact has become a very important part of the protection of environment. The protection of caves is possible only with the full knowledge and determination of the catchment area.

As there is no general method to be applied in any particular case the most appropriate one must be chosen after the investigation of the catchment area.

The Aggtelek karst area, well known for drip-stone caves in the north-east of Hungary, is not an individual karst area but a continuous part of the Slovakian karst. The largest cave is the Aggtelek or Baradla cave, a part of which (Domica branch) stretches over the border between the two countries.

We investigated the Hungarian part of the catchment area of the cavity system only, because the Domica part can be studied separately.

According to our present kowledge the Baradla cavity system is 23 kilometers long and can be considered to be a subsurface stream system. The segments having permanent streams are in fact subsurface river beds and other parts with solution tunnels widening during flooding are intermittent river beds. This latter gives way to the development of a lower cave. Some tunnels of the cave are continuations of surface dry valleys in front of swallow-holes.

As most of the swallow-holes (ponors or streamsinks can be found at the border of open and half covered or open and covered karst areas, non karst territories belong to the catchment area of the cave as well.

The Baradla cave represents an individual karsthydological system. No traces of any link between the Baradla and any other cave of the Aggtelek region have been found so far.

In general the water system of homogenous karst areas is a communicative system just like communicating vessels, but experience shows that individual cavity systems can develop without the presence of impermeable rock wedging. The development of lithoclases into cavities and whole cavity systems is affected by many factors (quality of rock, stratigraphy, structure, surface features, hydrography etc.).

The formation of individual or partly individual cavity systems within one block of rock is possible. Furthermore, segments of the cavities can be filled in temporarily or permanently.

The investigation of the Baradla cave can only be possible bearing in mind the above introduction.

The karsthydrological system, as it is strictly three-dimensional, must be considered as a block of catchment area from the point of view of water supply of the drainage area. In this way the surface catchment area is only one part but by no means the most important part of the block's water supply.

Water infiltrating into karst rocks but not reaching great depth comes from surface runoff. Thus all modification in cavity formation is due to the changes in water quality from any interference from the surface. Therefore the determination of the catchment areas of caves, owing to their large size and importance, is an essential part of the study in these areas.

It is surprising that the catchment area of this long explored cave has not been thoroughly investigated. In 1831 Imre Vass published a review on the phenomena of the catchment area but no detailed work could be carried out for a hundred years.

The reasons are the following:

1. Data about the cave was scarce.
2. There was no map of proper scale.

A survey of G. Stömpl (1923 – 27) did not touch upon the characteristics of the catchment area.

E. Dudich (1931) published exact but only occasional observations about the water in the area. According to him the swallow-hole at the Aggtelek entrance of the Baradla cave is fed by rainwater temporarily only and water gathers in the baulks of Bagolyvágás and Fekete-tó. He also points out that there are at least 6 or 7 places where water can get into the cave. He states that exogene contacts are uncertain.

S. Jaskó in his hydrological survey doesn't deal with the surface catchment area.

The very first thorough study on the catchment area from the point of view of karstology and speleology was published by H. Kessler (1938). He noticed that a large part of the catchment area was covered by permeable gravelled clay. The total extent of the catchment area, a part of which belongs to Slovakia, is 36.19 sq. kilometres in which 13 streamsinks have 13 individual subdrainage basins. According to him the drainage tributary arms of the cave are on the right of the main tunnel (in his opinion the Büdöstó Domica tunnel is part of the main tunnel) because the southern slopes of the hills drain the water to the lowlands without an outlet and through sinkholes the water is introduced into the tributary tunnels on the right. His identification of the ties between the cave tunnels and the swallow-holes has proved to be reliable with the exception of the Szárhegy streamsink which feeds the Béke cave.

Later on L. Jakucs dealt with the connection between the catchment area and water outlet of the cave stream (1951, 1956, 1963...) He proved that at present there is no connection between the Béke and Baradla cave. He presumed that the Róka cave is fed by the Bábalyuk streamsink and also determined the catchment area of the Béke cave. In this way the direct connection between the Szárhegy swallow-holes and Béke cave was clear.

Determining the boundary of the catchment area by surface morphology he states, that "the boundary of catchment areas in non karst areas is clearly indicated by the surface dividing ridge". He has made some further statements of vital importance.

"The cave streams of the Aggtelek area are fed by the water of two different type of catchment areas. The permanent and basic discharge comes from descending water (A type)". "The amount of B type water which comes from non karst areas, fluctuates in the water outlet". In this way he made a distinction between karst and non karst surfaces in the catchment area. He saw that non karst surfaces are covered by impermeable clay. The average altitude of dividing ridges in these areas is 375 metres. According to his meaurements 4.5 sq. kilometres of non karst catchment area belong to the main tunnel (Domica) which is smaller than the area outlined by Kessler. Jakucs took the non karst surfaces into consideration only and took away 70 per cent as the catchment of Bábalyuk, the water of which is not discharged into the main tunnel. Jakucs found that the non karst catchment area of Retekág is about 0.8 sq. kilometre. Rainwater seeps under the karst into the Jósva valley from the 21 sq. kilometre plateau, covered by Pannonian deposits.

L. Jakucs found strong correlation between the average width of the erosion tunnels (Mb) and the index number of non karst catchment areas (Tv). The mb indicates the width of tunnels per sq. metre of the catchment area.

$$mb = \frac{Mb}{Tv}$$

"If the equation is correct today, it had to be correct in the past as well". I.e. "if we measure the width of a tunnel in higher profiles we can determine the size of the earlier catchment area". Investigations of Jakucs indicate that the slight widening of tunnel profiles refers to a certain enlargement of the catchment area, probably as a result of the valley development.

In our investigations we determined the extension of surface catchment area by maps and local field work. In the case of karst, map work in itself is not satisfactory because the boundary of the catchment area is not clear and there are almost horizontal plateaus on the non karst areas, which also belong to the investigated territories. Dividing ridges can be drawn by local observation during rainfall only.

The dividing ridge thus determined surrounds areas which are very different in hydrologic and hydraulic properties. Some areas definitely drain towards the Baradla cave but the direction of drainage in other areas is not certain.

The surface runoff of the mapped catchment area outside Hungary is by no means drained by the Baradla system and there is no use taking that area into consideration. On the other hand not all seepage water reaches the Baradla cave. The boundary of the theoretically determined catchment area in Hungary is different from that of Kessler's.

To determine the boundary on Pliocene gravelled clay is relatively easy. East of the border the dividing ridge meanders at an altitude of 357 – 377 metres. The ridge passes between the plains of Hármashatár, Hidegvízoldal, Rozsnyói-úti-bérc and Bagolyvágás. The average length of a meander curve is 0.5 kilometre. Thus the catchment area of the cave is separated from the catchment area of Szuha patak, Trizs patak and Csörgős patak. Further on the direction of the boundary of the catchment area turns to the southeast, separating Fekete völgy in the north from the Imola streamsink's and the Fekete stream's catchment area. At the top of Kerekerdő the altitude of the boundary decreases (353 metres) and then turns north again at an altitude of 375 metres. The boundary in its total length connects areas which are temporarily without an outlet (Nemecsek kaszálója, Konkolyos, Nádas tó) but during heavy rainfall the surface runoff diverges in two directions. At the foot of Szomor-hegy there is a row of dolines where the boundary reaches a half covered karst area and from there on the direction of runoff is difficult to determine. There are open and half covered karst areas.

Water infiltrates through the dolines from the northern side of the hill and geomorphology and stratigraphy show that water is probably

collected by the lower tunnels of the Baradla cave. All water from the northern slopes of Szárhegy goes to the Hidegvölgy row of dolines and its infiltration into the Baradla cave has already been proved. It is also clearly indicated by the former swallow-hole at the Vöröstó entrance of the cave. The flow of infiltrating water into the dolines at Vöröstó is not certain. Probably it is distributed between the Baradla and Béke cave. In this case there is subsurface bifurcation.

The surface runoff above the Jósvafő end of the cave directly flows into Farkastorok-völgy (Jósva patak) and partly Kecső-völgy (Kecső-patak). The northern boundary of the catchment area passes along the open karst area. At Somostető it reaches an altitude of 438 metres then turns to the west and meanders until the Baradla top which is higher than 391 metres.

The Baradla valley is cut by the boundary of the catchment area at the dividing ridge of the row of dolines in the valley. This means that the direction of runoff is marked to the north but not to the south. Probably water infiltrates to the south and that part of the valley also belongs to the catchment area of the Baradla cave. Further on the southeastern slope of Poronyatető belongs to the catchment area of the valley within Hungary.

According to our studies the outlined catchment area of the Baradla cave can be divided into 16 sub-drainage basins. The determination of surface catchment areas in karst areas is different from that of non-karst's. This is because karst areas very often direct surface runoff into depressions that do not have permanent surface swallow-holes. But at the same time if these areas are connected with the water systems of cavities they become part of subsurface water systems. To prove these connections directly is very difficult even with the use of fluorescent dye tracers. In our present study we have relied on the results of previous water dying and other methods of investigation.

We have set up four categories of sub-drainage basins in the catchment area:

A.) Drainage basins of open and half covered karst areas.

I. A group of the drainage basins belongs to the water system of the Baradla cave.

II. A group of the drainage basins which probably belongs to the Baradla water system but the connection has not been proved.

B.) Drainage basins on covered karst areas. Karst blocks are deep and sunk along tectonic faults. The area is covered by a thick layer of Pliocene gravelled clay or coarse grained sand deposits. Valleys are dry, in some places terraced. Surface streams can be observed as far as the edge of the open karst area, where water disappears through active swallow-holes. The swallow-holes can be open or filled in with permeable deposits. A great amount of flint gets into the caves through these sinkholes and this is significant in forming the tunnels.

C.) A part of the sub-drainage basins is complex, because they are partly on covered karst areas and on the other hand the southern slopes and valleys of open and half covered karst areas also discharge water in their direction. In both cases these complex areas collect surface runoff and the water disappears in one common swallow-hole.

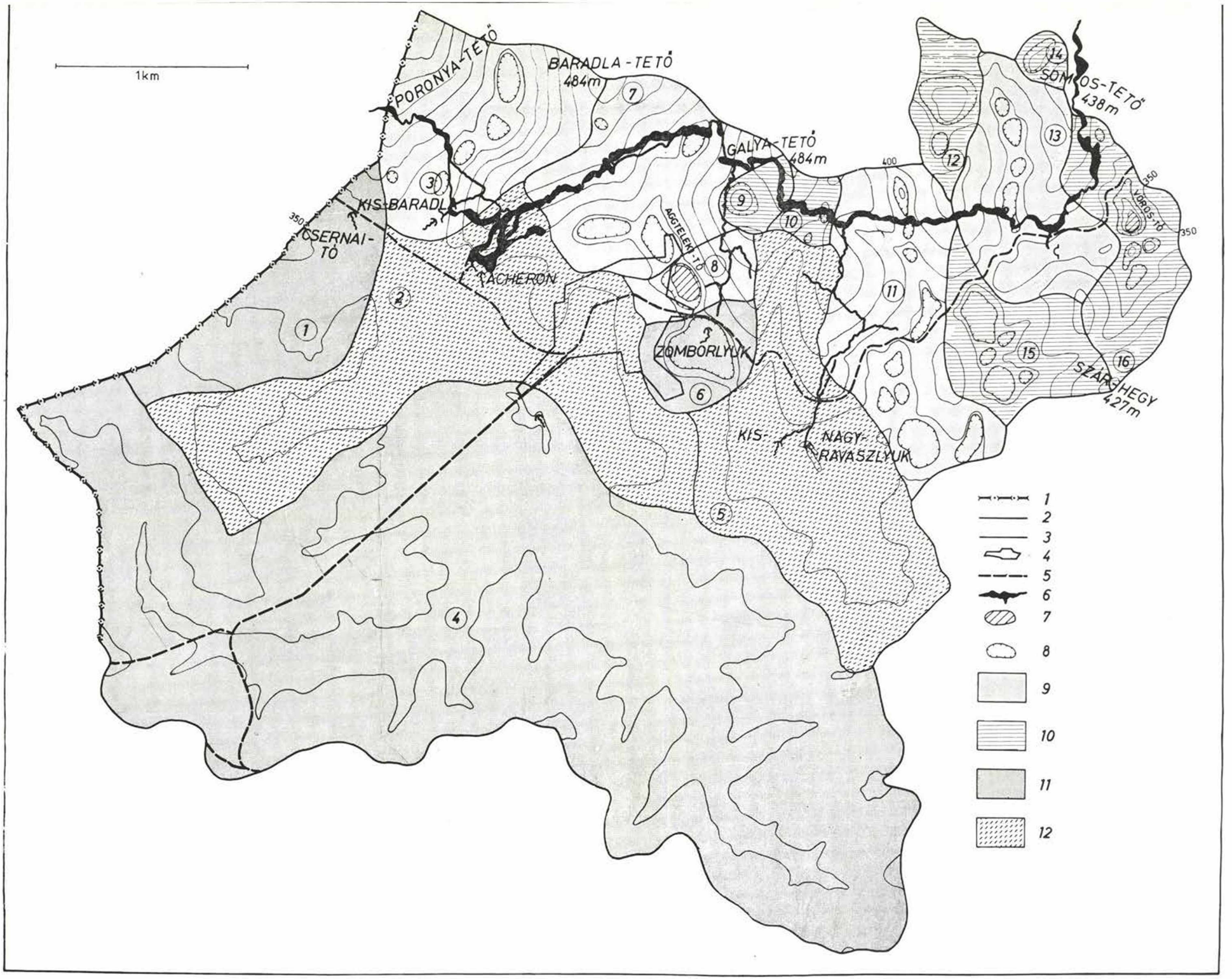
Bearing in mind the above mentioned, the 16 sub-drainage basins in the Baradla catchment area can be characterized as it follows:

No 1. The drainage basin of Csernai-tó swallow-hole: The smaller part of the whole basin belongs to Hungary. Most of the area is covered karst, the valleys are normal, the hills flattened. The average relief energy is about 60 metres. The swallow-hole (which was obstructed earlier but is active at present) collects water and conducts it to the cave but the tunnels are not known. A considerable amount of water comes from the direction of Pányi-völgy, but the Slovakian part of the area is only partly karstic and so the area would rather belong to category C.

No 2. is a complex C category sub-drainage basin, which conducts water from the "Baradla front" in the south-west and Keresztfamegi baulk in the south-east into the Acheron streamsink. During heavy rainfall the area forms one basin with the sub-drainage basin No 4. Morphologically there is only an 1.2 metres high ridge between the two basins. When water outlet is at its peak a large amount of water from basin No 4. reaches the Acheron swallow-hole. The surroundings of the swallow-hole has been artificially filled and in consequence of this there is no deposition in the shaft. The northern middle part of the basin is open karst, but very little water comes from there.

No 3. belongs to category A/I. Water from the southern part of the Baradla valley, the eastern part of Poronyatető and western part of the Baradla ridge infiltrates towards the Baradla cave or is directly conducted to the Rubikon tunnel. The swallow-hole is not separated by a high elevation on the surface from the Acheron and Csernai tavi swallow-holes. The water of the catchment area partly reaches the upper and partly the lower tunnels of the cave.

No 4. is the largest basin of the cave's catchment area. The network of valleys is normal, the surface undulation is well proportioned with hillocks in the north and hills of covered karst areas in the south. Water gets into the Bábalyuk sinkhole from Hollófészek-völgy in the south-west and Feketető-völgy in the south-east. Relief energy is not significant but the Pannon surface is well proportioned. The "plateaus" in between the valleys are not steep and surface runoff is bad. There are intermittent lakes and muddy areas (Kardos-tó, Kender-tó etc.). The water and gravelled deposit forming the main tunnels of the cave, comes from this basin. The valleys are mostly dry and waterflow in the riverbeds is strictly limited to the period of rain and the following 48 hours. Most frequently water disappears in the narrow Bábalyuk sinkhole but in case of heavy rainfall over-



The water catchment area of Baradla Cave. 1. Boundary between Czechoslovakia and Hungary 2. Boundary of the catchment area 3. Boundary of sub-catchment area 4. Settlement 5. Road 6. Cave tunnel 7. Doline-lake 8. Doline 9. The Baradla catchment area which developed on open and half-covered karst areas 10. The catchment area probably belonging to the Baradla water system, which has developed on open and half-covered karst areas 11. Catchment area on covered karst 12. The catchment area which developed partly on open, partly on covered karst areas

flows into the neighbouring holes, through basin No 2. According to some hypothesis the Bábalyuk sinkhole might conduct water to Róka cave, but more likely to the lower tunnels of the Baradla cave. In this latter case Bábalyuk hole proves a subsurface decapitation. South of the southern boundary of the catchment area several gullies are to be found in the upper parts of the valleys. The development of valleys to the north prove the shifting of the boundary of the catchment area to the north. Presumably the extent of the catchment area is gradually decreasing. In the east sub-drainage basin No 4. is contiguous with the valley system of Nagy-völgy, which belongs to the catchment area of Béke cave.

No 5. The area in the south is typical covered karst which gradually turns into a half covered karst area. Surface runoff from the half covered karst area (Almás-völgy) meets the water of the dry valley of Konkolyos baulk at its deepest point. Relief energy is low, less than 45 metres. At the edge of the open karst area Kisravaszlyuk and Nagyravaszlyuk swallow-holes collect the water in a deep gully, while the largest tributary of the cave (Retekág) joins them. On the surface of this sub-drainage basin the extent of flint is fairly large (in other places it is usually covered by Pleistocene clay) and a lot of water gets into the cave through the shafts. Thus the widening of tunnels is fast.

No 6. is a small, well demarcated basin. The karst area is covered by flint and clay. The size of the sub-drainage basin does not indicate the measures of Törökmecsetág tunnel, which is behind Zomborlyuk swallow-hole – a classically developed ponor.

No 7., 8. Water on this open and half covered karst area collects in five separate dolines. Owing to the stratigraphy and position of the basin, water is probably conducted into the Baradla cave. The drainage basin of Aggteleki-tó must have been linked with one of the tributary tunnels of Törökmecset, that is why we have separated catchment area No 8.

No 11., 13. Both sub-drainage basins are half covered karst areas with many dolines. There are no open holes in the dolines, thus seepage water reaches the Baradla system (probably the lower cave) but the existence of some link with Béke cave must not be left aside. The dolines and slopes of catchment area No 11. are covered by a thick layer of clay. The surface was probably a covered karst area in the near past. The water in sub-drainage basin No 13. must have been collected by the former swallow-hole near the Vöröstó entrance.

No 9., 10., 12., 14. are very small sub-drainage basins. Each of them has only one or two dolines and the water infiltration into the Baradla cave is only supposed. The fact, that no hydrological connection can be observed towards Kecső-völgy, seems to be an indirect proof.

No 15., 16. sub-drainage basins are open and half covered karst areas with a lot of dolines. The water is separately collected by the dolines. Further way of water flow or infiltration is not well known. These complex basins with dolines can have connection with the water system of Béke cave. If the sink-holes in the surroundings of Vörös-tó conduct water into the Béke cave, an odd situation can be observed. Namely, the water

from the surface above a cave (which is the Baradla cave in our case) is conducted into an other cave. The only explanation of the curious phenomenon is that two separate cavity systems are too near to each other.

The present determination of the extent of the Baradla catchment area is far more accurate than the earlier ones. According to our measurements by planimetre, the extent of the catchment area and sub-drainage basins is as follows:

Sub-drainage basin	Category	Extent (sq.km)
No 1.	B	0.7242
No 2.	C	2.1028
No 3.	A/I	0.9207
No 4.	B	7.0645
No 5.	C	1.5591
No 6.	B	0.2831
No 7.	A/I	0.8587
No 8.	A/I	0.2070
No 9.	A/II	0.1056
No 10.	A/II	0.0938
No 11.	A/I	0.9721
No 12.	A/II	0.2443
No 13.	A/I	0.7170
No 14.	A/II	0.0607
No 15.	A/II	0.4813
No 16.	A/II	0.5119
Total theoretical extent of the catchment area of the Baradla cave in Hungary		*16.9068 sq. km*

Total extent of the catchment area with regard to the set up categories (A/I–II, B, C):

A.) Catchment of open karst areas	5.1731 sq.km
I. Water conducted into the Baradla system	3.6755 sq.km
II. Water probably conducted into the Baradla system	1.4976 sq.km
B.) Catchment of covered karst areas	8.0718 sq.km
C.) Catchment of open and half covered karst areas	3.6619 sq.km
Total	16.9068 sq.km

A detailed determination of the catchment area of the Baradla cave provides an opportunity for us to carry out karst hydrological estimations, we can outline the area to be protected and we can draw conclusions to the further geomorphological evolution of the surface.

On the southern boundary of sub-drainage basin No 4. several gullies are rapidly being formed. This indicates the uplift of the surface and thus the

catchment area of Retek-ág and some other tunnels is growing. This morphological deduction fits in well with the statements of L.Jakucs (1956).

The uplift of this part of the watershed is proved by L. Bendeffy, purely from the data showing the changes of altitudes of the trigonometry network system within ten years. According to his measurements a strip on the south of the catchment area is rising by 0.05 millimetre per year and the southern part of the open karst area by 0.067 mm quicker than the area with swallow-holes between the two stripes. The growing difference in altitude increases the water discharge into the shafts.

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РЕЗЮМЕ

ВОДОСБОРНАЯ ПЛОЩАДЬ ПЕЩЕРЫ БАРАДЛА НА ТЕРРИТОРИИ ВЕНГРИИ

По имеющимся сведениям аггтелекская пещера Барадла предотавдяет собой самостоятельную карсто-гидрографическую систему. Точное выделение границ поверхностной водосборной площади пещеры было произведено частично на основании рельефа и частично на основе карсто-гидрографических наблюдений. Поверхностная водосборная площадь включает большей частью территорию, покрытую толстым слоем некарстовых отложений, меньшая же её часть полупокрыта отложениями или же представлена открытым карстом. В соответствии с этим водосборная площадь пещеры может быть разделена на такие части: 1. открытокарстовая, 2. покрытокарстовая и 3. полупокрытокарстовая. Такое разделение водосборной площади на части даёт возможность произведения карсто-гидрографических расчётов, сделать выводы по пещерной генетике и по истории её развития, а также выделить зону по охране пещеры на поверхности земли.