Water balance calculation method for urban areas, examples from Hungary

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Abstract: A new water balance calculation has been worked out that considers the effect of urbanisation. This calculation method was applied to evaluate the water balance of the historic centre of Budapest, for the Buda Castle Hill, where an intense network of cellars are found. The method, combined with hydrogeological tests and field measurements was also tested at other Hungarian cities, where underground structures are common, such as Eger, Pécs and Veszprém.

The calculation considers both natural and man-induced water sources. Besides the commonly used natural factors such as precipitation, evaporation, runoff, infiltration, etc. it also uses input parameters such as broken pipelines or sewer systems. The water losses of these significantly influence the natural water balance and provide additional and very often significant water input into the water system. The new method has key importance in the design and planning of remedial actions in historic cities, where infiltrating water endangers the built environment, cellars and natural caves. Another feedback of the method is the application of the results in the long-term planning strategy of public works supplying or using water (water works, sewer system, and energy sector).

Résumé: On a établi un nouveau calcul d'équilibre de l'eau qui considère l'effet de l'urbanisation. Cette méthode de calcul a été appliquée pour évaluer l'équilibre de l'eau du centre historique de Budapest, pour la colline de château de Buda, où un réseau intense des caves sont trouvés. La méthode, combinée avec les essais et les mesures sur le terrain hydrogéologiques a été également examinée à d'autres villes hongroises, où les structures souterraines sont communes, comme Eger, Pécs et Veszprém.

Le calcul considère des sources d'eau normales et homme-induites. Sans compter que les facteurs normaux généralement utilisés tels que la précipitation, l'évaporation, l'écoulement, l'infiltration, etc. il emploie également des paramètres d'entrée tels que les canalisations ou les réseaux d'égouts cassés. Les pertes d'eau de ces derniers influencent de manière significative l'équilibre normal de l'eau et fournissent additionnel et l'eau très souvent significative a entré dans le système de l'eau. La nouvelle méthode a l'importance principale dans la conception et la planification des actions réparatrices dans les villes historiques, où l'eau d'infiltration met en danger l'environnement établi, les caves et les cavernes normales. Une autre rétroaction de la méthode est l'application des résultats dans la stratégie de planification à long terme des travaux publics fournissant ou employant l'eau (travaux d'eau, réseau d'égouts, et secteur d'énergie).

Keywords: Urban geosciences**,** case studies, hydrology

INTRODUCTION

The classical method of water balance calculations considers precipitation on the input side and runoff, evaporation and infiltration on the output one. This method, however, does not bring satisfactory results in urban areas due to the fact that the effects of urbanization – first of all the public utilities – may significantly change the water system. Below I am publishing the results of calculations carried out in Hungarian cities, using the method (Hajnal 2002, 2003) that was elaborated for the Castle Hill, Buda.

GROUPS OF WATER TYPES

The first step of the water balance calculation method that takes into account the effects of urbanization is to collect and structure all the possible water data. These fall into the domain of geology, geotechnics, meteorology and (the development of) public utilities.

In a given settlement the following classes of natural water sources may occur:

- precipitation,
- runoff,
- evaporation,
- infiltration.

Man-induced classes of urban water "sources" are from public utilities:

- water pipelines,
- sewage,

- district-heating.

The appearance of both types of water can be very diverse and include:

- springs and water overflows,
- water in bore-holes of geotechnical purposes,
- cellar water (regular and constant flooding),
- water of drilled and dug wells,
- water of ground-water level observation wells, Figure 1,
- water of draining-channels.

Figure 1. Measuring water level, temperature and pH value of the ground-level observation well in Pécs

It can be noted that these groups are not based on the classic hydrologic system (surface, subsurface, ground, confined, etc. waters), but are made according to the simplest groups of the measurable and observable data. The origin of certain water types may partly or totally correspond. For example, the water of a natural spring in a city hillside might be joined by the water lost from a public utility; alternatively the opposite may occur at a water overflow, whereby the water from an old undetected fault of the pipeline system can mix with water coming from the infiltration of precipitation. Figure 2.

Figure 2. Periodic water overflow in a retaining wall (Veszprém)

THE IMPORTANCE OF WATER LOSSES OF THE PUBLIC UTILITIES

Measurements and calculations proved that the water system of a particular urban area or that of a city quarter is basically influenced by the losses of the public utilities.

Before presenting the essentials of this method we shall look at a few examples that justify this statement:

- Examining the data series of ground-water level observation wells (Budapest, Pécs and Eger) it can be stated that the water level diagram never follows (not even with a delay) the changes of the yearly precipitation (Hajnal 2005).
- The yearly total amount of the changes in the water level in single wells significantly exceeds the yearly amount of precipitation.
- In Hungarian settlements we rarely find ground-water level observation wells that when examined using hydrological statistical methods can be considered to have a free flow regime (examinations of consistency and homogeneity) (Réthási 1974).

In the water supply the amount of water that is regarded as lost is that which is not used for useful purposes (e.g. flushing of the pipeline network). A spectacular but small proportion of this loss is generated by pipe ruptures, when a considerable amount of water, with high intensity is increasing the water loss, but for a short period of time. As opposed to these losses, the small sized defective sites (connections to houses, defects of the junctions) cause the filtration of small amounts of water, but due to their large number and long lifetime (possibly several years) they may represent 60% of the sales balance. For example, in a defective site of diameter of 5 mm the filtration of the water amounts to 25 l/min, and such anomaly can occur at 1 or 2 places in a pipeline of 1 km. When not measuring the loss in a given area, the Hungarian waterworks companies apply a rule of thumb, which determines the loss as 10% of the water amount piped into (pipelines) or drained away (drains) from the area (Hajnal 2002, 2003). (There are areas though where this proportion might be as high as 50%.)

WATER BALANCE CALCULATION

The calculation method presented is for the Castle Hill of Buda. The extent of the catchment territory of the Castle Hill totals 920,000 m^2, of this the area of the Plateau is 400,000 m^2 and the area of the Castle Slope is 520,000 m^2. The calculation takes into account the pipeline input based on area ratio. The area of the continuous cave system below the Plateau is 18,000 m^2, the area of the separate cavities amount to 4,000 m^2.

The schematic cross-section of the Plateau is shown in Figure 3, the flowsheet of the calculation is in Figure 4.

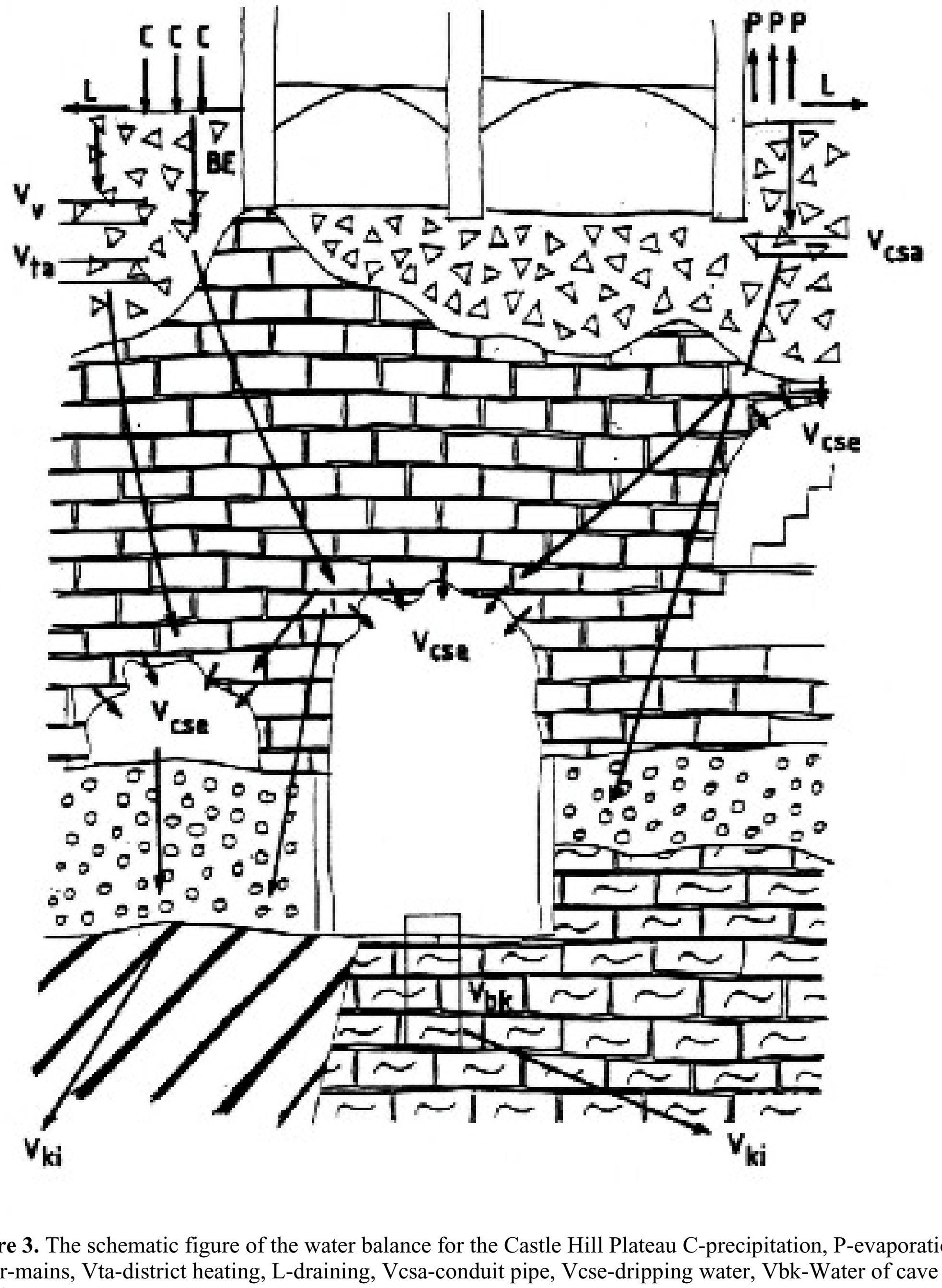

Figure 3. The schematic figure of the water balance for the Castle Hill Plateau C-precipitation, P-evaporation, BE-infiltration, Vv-Water-mains, Vta-district heating, L-draining, Vcsa-conduit pipe, Vcse-dripping water, Vbk-Water of cave wells, Vki-water overflows

The steps of the calculation

Drainage was calculated with a weighted draining factor $\alpha = 0.8$.

Volumetric precipitation on the area P is calculated from the annual precipitation P_a:

$P\ (m^3/year) = A_p\ (m^2) \bullet P_a\ (mm/year)$;

From this, the evaporation E is taken as:

$E = 1/3 \bullet P$;

The drainage, D is calculated from:

$D = \alpha \bullet (P - E)$, if $\alpha = 0.8$, $D = 8/15 \bullet P$

and the infilation, I_p from:

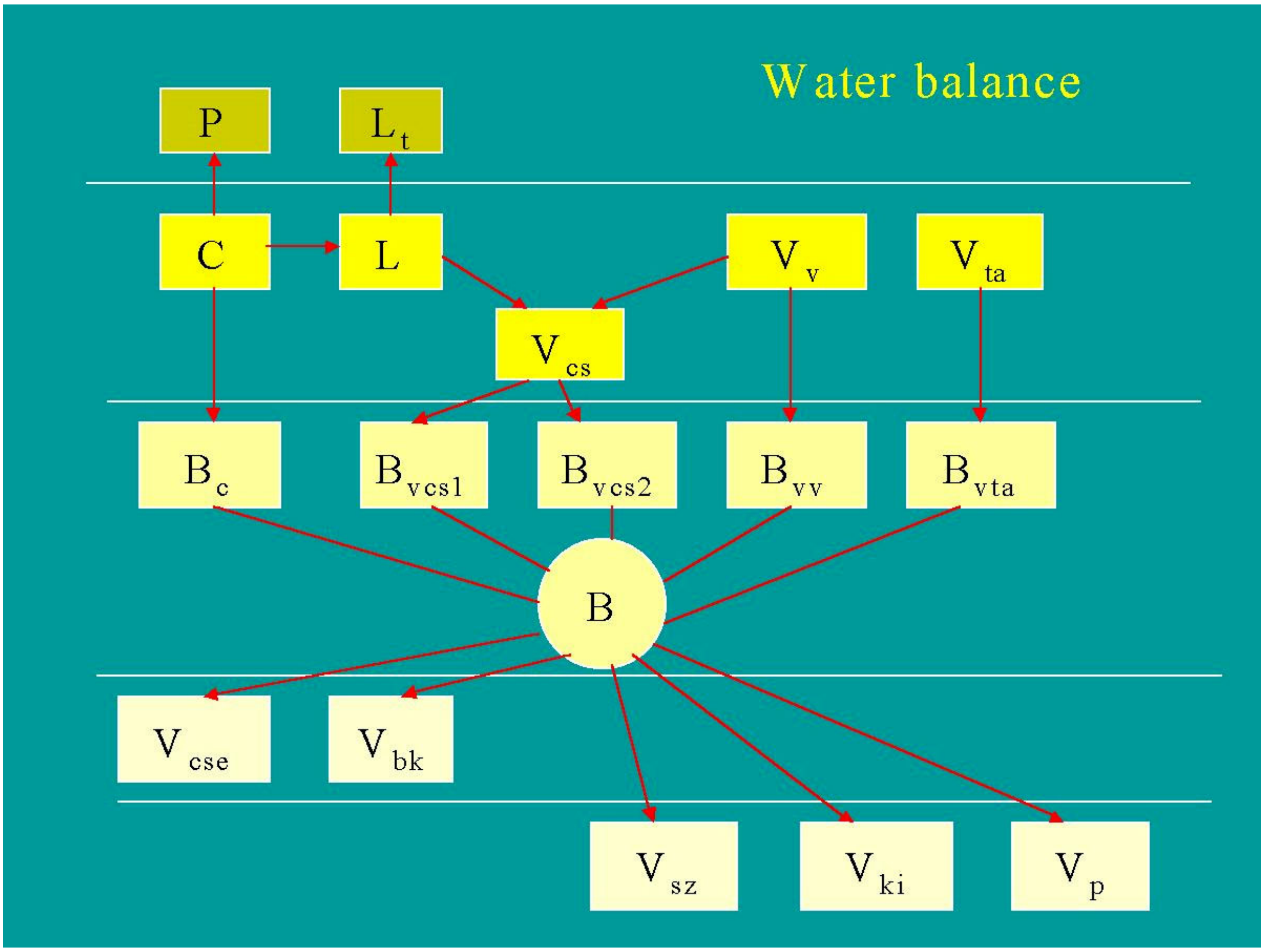

Figure 4. The flowsheet of the water balance calculation that takes into consideration the effects of urbanization.

$I_p = P - E - D$, $I_p = 2/15 \bullet P$;

The loss of water-mains, I_{wm}, in the area ratio Plateau/(Plateau + Slope) was determined by:

$I_{wm} = (40/92 \bullet W)/10$, $I_{wm} = W/23$

and the amount of water infiltrating, I_{wdh}, from the loss of district heating, W_{dh}, determined from:

$I_{wdh} = 2/3 \bullet W_{dh}$;

The waste water loss from precipitation, I_{pcp} was evaluated from:

$I_{pcp} = (0.9 \bullet D)/10$, $I_{pcp} = 0.048 \bullet P$,

with the waste water loss, I_{wmcp} from the water-mains obtained from:

$I_{wmcp} = (40/92 \bullet W - I_{wm})/10$, $I_{wmcp} = 9/230 \bullet W$;

The loss from all the waste water, I_{cp} was taken as

$I_{cp} = I_{pcp} + I_{wmcp}$;

and all the infiltration into the Plateau determined from:

$\Sigma I_p = I_p + I_{wm} + I_{wdh} + I_{cp}$;

The infiltration into Polgárváros, $I_{pol,}$ was evaluated from the ratio of the areas:

$I_{pol} = 31/40 \bullet I_p$;

From this all the water amount getting into the cavities, $I_{dc,}$ was calulated:

$I_{dc} = 22/310 \bullet I_{pol}$;

followed by the infiltration into the Great Labyrinth, I_{gl}

$I_{gl} = 9/11 \bullet I_{dc}$;

Finally the water amount getting into the separate cavities, $I_{sc,}$ was detemined:

$I_{sc} = I_{dc} - I_{gl}$;

RESULTS IN HUNGARIAN CITIES

Each city has its own special character which modifies the flowsheet. Significant differences can depend on whether the drainage system is unified or separated – Fig. 4. shows an example for the unified, while Fig. 5. shows sample precipitation drainage ditch in Pécs. An increasing parameter can be e. g. a karst spring of large discharge (Figure 6.) or a system of cavities with public utilities (Figure 7.), while decreasing parameters can be a system of tunnels with drainage (Buda), as well as backfilled cellars (Eger and Buda).

Figure 5. Precipitation drainage ditch (Pécs)

Figure 6. Karst spring „Tettye” in Pécs

Retaining walls, drainage systems and pavements on the slopes also basically influence the water system conditions. (Figures 8 and 9).

Depending on the local circumstances it is to be decided whether infiltration deriving from losses should be defined on the basis of area ratio of pipelines, or the length of the pipeline. This latter method has been applied in Pécs.

Figure 7. The cave system of the Castle Hill of Buda, water inflow deriving from the defect of public utilities

Figure 8. Soaked retaining walls in the castle of Veszprém

Figure 9. Wetted impasse in Veszprém

Table 1. Results of the calculation for seven areas

Data	Castle Hill of Buda		Rózsadomb (Budapest)		Eger	Pécs	Veszprém
	Plateau	Slope	József Hill	Csatárka			
Rock	Travertine	Buda Marl	Travertine, Buda Marl, Kiscell Clay		Rhyolitic tuff	Travertine, Sarmatic limestone, Marl	Dolomite
Area (m^2)	400,000	520,000	1,652,900	2,518,035	4,500,000	375,000	20,800
Precipitation (mm)	540		513		647	672	548
Water input (m^3/év)	568,755	739,381	1,190,203	2,506,222	1,683,394	131,391	13,704
Input factor (input/area)	1.42		0.72	0.99	0.37	0.35	0.66
Infiltration (m^3/year)	150,270	192,920	400,656	709,730	685,725	37,598	7142
Years	1996-2000		1992-2001		1995-1999	1994-2003	1996-2003

SUMMARY

The water system of a given settlement is basically determined by the losses of the public utilities. Man-induced waters endanger the built environment, the monuments as well as the natural values of a city. The water calculation method that takes into consideration the effects of the urbanization may provide useful data for the necessary regional planning, environmental protection actions and the establishment of a monitoring system.

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