HYDROLOGY REPORT ON WATER BALANCE OF LAKE BALATON

GY. VARGA1, G. KRAVINSZKAJA2

ABSTRACT. – Hydrology on water balance of lake Balaton. From the mid 1960s the number of occurrences of drier-than-average years have increased when compared to the preceding period. It also deserves attention that these years tend to appear consecutively (3, 7, and 4 consecutive years during this time). This phenomenon results in cumulative water deficit that affects the water-circulation of the lake negatively as well as causing significant and persistent droop in both the water-supply and water-level. Characteristic and enduring changes can be diagnosed regarding the change of inflow over time. The most prominent of these is the decline that began in the early 1970s and continues to our day. This decline can most likely be credited to the simultaneous occurrence of a number factors affecting down-flow.

Key words: precipitation over the lake surface, inflow to the lake, cumulative water deficit, significant and persistent droop in both the water-supply and water-level

1. Introduction

Water budget of the Lake Balaton can be followed to study water quantity changes throughout time. The following elements of Lake Balaton water budget are taken into account for a certain period of time:

\[ \Delta W = (P+I) - (E+O+W_u) \]

where

- \( P \) precipitation over the lake surface
- \( I \) inflow to the lake
- \( E \) evaporation from the lake surface
- \( O \) outflow from the lake (through Siófok sluices)
- \( W_u \) irreversible water use (the difference of water intake and effluents)
- \( \Delta W \) increment of water storage in the Lake
- \( \Delta W_N \) natural change of lake water storage

\[ \Delta W_N = (P+I) - E \]

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Water budgets that can be considered reliable for the analysis of the water balance of Lake Balaton are available from 1921 both in monthly and annual detail. This means that for each of the elements of the water budget we have accumulated a 91-year long (1921-2011) time series. In Table 1 below we provide the mean and the extreme values for the different factors.

Table 1. Factors of Lake Balaton water balance

<table>
<thead>
<tr>
<th>Elements of water balance</th>
<th>Minimum</th>
<th>Mean</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation over lake surface (P)</td>
<td>309</td>
<td>617</td>
<td>929</td>
</tr>
<tr>
<td>Inflow to the lake (I)</td>
<td>293</td>
<td>864</td>
<td>1974</td>
</tr>
<tr>
<td>Evaporation from the lake surface (E)</td>
<td>723</td>
<td>900</td>
<td>1073</td>
</tr>
<tr>
<td>Natural change of lake water storage (ΔWₙ)</td>
<td>-180</td>
<td>581</td>
<td>2031</td>
</tr>
<tr>
<td>Outflow from the lake (O)</td>
<td>0</td>
<td>564</td>
<td>2031</td>
</tr>
<tr>
<td>Irreversible water use (ΔWₜ)**</td>
<td>15</td>
<td>29</td>
<td>51</td>
</tr>
</tbody>
</table>

* 1 mm = 600 000 m³ water; ** data for period 1971-2011

It is evident that among the factors influenced by the forces of nature evaporation shows the least amount of variance and inflow shows the highest. Lake Balaton is a lake with significant outflow, the average outflow per year is close to the average yearly amount of precipitation over the lake surface. Since 1863 the outflow is regulated through the Sió-canal. Both the amount and time-span of water-tapping from the lake are determined by the needs of water management and the effectual water-level-control regulations.

2. Water input

2.1. Current situation

On the input side of the water balance equation we have the precipitation over the lake surface and the inflow to the lake.

2.1.1 The amount of precipitation over the lake surface

The amount of precipitation over the lake surface is established from the measurement data of 10 measuring stations around the lake by means of area averaging. On figure 1 we illustrate the yearly amounts of precipitation over the lake surface.

It can be stated that there are no significant variations in the yearly amounts of precipitation over the lake surface. Between the mid 1960s and the mid 1990s the time series shows a slight declining trend. It is noteworthy that between 2000 and 2011 there were 8 years where the amount was under the average. The fact that the historical records (both maximum and minimum) occurred in consecutive years is also remarkable. Figures 1 and 2 illustrate this.
Figure 1. Yearly sums of precipitation over the lake surface.

Figure 2. Time series of precipitation over the lake surface “ranked”.
For the assessment of the amounts of precipitation over the lake surface we heeded the recommendation of the WMO (WMO, 1983) which suggests that long term changes in meteorological parameters be presented and evaluated based on 30-year averages that skip ahead with each passing decade. Table 1 and Figure 3 are compiled and drawn up according to this principle.

**Table 2.** 30-year averages of precipitation over Lake Balaton’s surface

<table>
<thead>
<tr>
<th>Time period</th>
<th>Yearly mean precipitation (mm/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1921-1950</td>
<td>632</td>
</tr>
<tr>
<td>1931-1960</td>
<td>623</td>
</tr>
<tr>
<td>1941-1970</td>
<td>623</td>
</tr>
<tr>
<td>1951-1980</td>
<td>624</td>
</tr>
<tr>
<td>1961-1990</td>
<td>612</td>
</tr>
<tr>
<td>1971-2000</td>
<td>599</td>
</tr>
<tr>
<td>1981-2010</td>
<td>605</td>
</tr>
</tbody>
</table>

According to the data given in Table 1 for the entire time span of 1921-2011 there is a slow – non-significant – decrease in the 30-year averages from the 1960s. Based on the last 30-year mean value (1981-2010) this trend appears to be faltering.

Figure 3 shows that from the mid 1960s the number of occurrences of drier-than-average years have increased when compared to the preceding period. It
also deserves attention that these years tend to appear consecutively (3, 7, and 4 consecutive years during this time). This phenomenon results in cumulative water deficit that affects the water-circulation of the lake negatively as well as causing significant and persistent droop in both the water-supply and water-level.

2.1.2 Inflow to the lake and precipitation on the catchment area

When describing the inflow to Lake Balaton it is expedient to begin with a look at – from the standpoint of the lake’s catchment area – data of precipitation that will ultimately result in said inflow.

The amount of precipitation on the catchment area is established from the measurement data of 25 measuring stations by means of area averaging. Figure 4 illustrates the time series consisting of the yearly precipitation sums. The average for the entire period is 683 mm/year, the record high and record low values (395 and 992 mm) were registered in two consecutive years, 2010 and 2011 respectively.

It can be ascertained that the changes over time in this time series are very similar in their trend to those observable in the lake surface time series, however there are differences as well. In general it may be concluded that all the changes are more pronounced, e.g. the decrease in precipitation between the mid 1960s and mid 1990s – unlike the similar change in the lake surface data – was statistically significant here.

![Figure 4. Yearly sums of precipitation on the catchment area](image-url)
For the assessment of the amounts of precipitation on the catchment area we heeded the recommendation of the WMO (WMO, 1983) which suggests that long term changes in meteorological parameters be presented and evaluated based on 30-year averages that skip ahead with each passing decade. Table 2 and Figure 5 are compiled and drawn up according to this principle.

Table 3. 30-year averages of precipitation on Lake Balaton’s catchment area

<table>
<thead>
<tr>
<th>Time period</th>
<th>Yearly mean precipitation (mm/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1921-1950</td>
<td>700</td>
</tr>
<tr>
<td>1931-1960</td>
<td>701</td>
</tr>
<tr>
<td>1941-1970</td>
<td>705</td>
</tr>
<tr>
<td>1951-1980</td>
<td>697</td>
</tr>
<tr>
<td>1961-1990</td>
<td>672</td>
</tr>
<tr>
<td>1971-2000</td>
<td>658</td>
</tr>
<tr>
<td>1981-2010</td>
<td>662</td>
</tr>
</tbody>
</table>

Figure 5 shows that from the mid 1960s the number of occurrences of drier-than-average years have increased when compared to the preceding period. As mentioned in Chapter 1 it also deserves attention that these years tend to appear consecutively (3, 7, and 4 consecutive years during this time). This phenomenon
results in cumulative water deficit that affects the water-circulation of the lake negatively as well as causing significant and persistent droop in both the water-supply and water-level. We would like to emphasize the 4-year period between 2000 and 2003. The cumulative precipitation shortage of these four years neared the average yearly amount of precipitation and caused the most extreme deficit in the water balance in 80 years of data-gathering.

Inflow is the most substantial and at the same time the most inconstant element on the input side of the water balance equation. On Lake Balaton’s catchment area the lake surface and the total catchment area without the lake surface ratio is 1:9. The methodology for determining inflow has changed much with the building up of the observer-network and advancements and evolution in both the instrumentation and applied techniques in the last 90 years. One of the results of this change has been the decrease of the ratio of sub-areas within the catchment area where down-flow (which is the inflow from the lake’s standpoint) is estimated (usually using the method of hydrological analogy). Continuous water-level and discharge measurements have encompassed more than 90% of the catchment area.

Figure 6 demonstrates the yearly sums of inflow to Lake Balaton.

![Figure 6. Yearly sums of inflow to Lake Balaton](image)
Characteristic and enduring changes can be diagnosed regarding the change of inflow over time. The most prominent of these is the decline that began in the early 1970s and continues to our day. This decline can most likely be credited to the simultaneous occurrence of a number factors affecting down-flow. Firstly we should mention the corresponding decline in precipitation and the resulting deficit. However due to the cumulative nature of the precipitation deficit the decline in down-flow on the catchment area is significantly higher than the decline in precipitation, which in turn resulted in the significant decrease of the inflow to Lake Balaton. The consecutive occurrence of drier-than-average years – that could be referred to as dry-year-groups – reduced not only the surface water supply but the subterranean as well. Because of this latter reason some of the historically reliable surface streams (being fed mainly from underground sources) experienced a loss in their base-discharge, others have begun to see dry periods.

Another noteworthy factor is the effect of the pumping out of karst-water from the Transdanubian Mountains (these were done to enable safe bauxite-mining) from the 1950s to the 1990s. The majority of the removed water was then let into Lake Balaton through the streams of the Tapolca-basin. The peak of the pumped quantity was in the mid 1970s (projected over the surface of the lake it was 100-110 mm/year). However the pumped water quantities did not directly cause the total inflow to increase, because other streams declined in their average discharge or even dried out periodically due to the drop in karst-water level. According to estimates by hydrological experts only about 60-80% of the pumped water was a true surplus in the lake. As the mining industry was downsized and eventually operations seized so did the inflow decrease as well, and in 1992 pumping of mine-waters stopped completely. The subterranean regeneration of the karst-water reservoir is not yet complete, but in the past two years the water levels have risen considerably, old and dried-out springs came back to life again.

The changes of inflow to the lake were probably also affected by the Kis-Balaton Water Protection System, which has been in operation since 1985 and by increasing the open water surface it causes a loss through evaporation that means less inflow to Lake Balaton itself. This effect is likely even more significant in drier-than-average years (previous expert estimates say it may reach 20-30 mm/year when projected over the surface of the lake).

On Figure 7. it is visible that except for the year 2010 none of the years of the new millennium reached the long-term average in the inflow to the lake.

For the assessment of the changes in inflow to the lake we also heeded the recommendation of the WMO (WMO, 1983) which suggests that long term changes in meteorological parameters be presented and evaluated based on 30-year averages that skip ahead with each passing decade. Table 3 and Figure 8 are compiled and drawn up according to this principle.
Figure 7. Time series of inflow to the lake “ranked”

Table 4. 30-year averages of inflow to the lake

<table>
<thead>
<tr>
<th>Time period</th>
<th>Yearly mean inflow (mm/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1921-1950</td>
<td>937</td>
</tr>
<tr>
<td>1931-1960</td>
<td>919</td>
</tr>
<tr>
<td>1941-1970</td>
<td>979</td>
</tr>
<tr>
<td>1951-1980</td>
<td>954</td>
</tr>
<tr>
<td>1961-1990</td>
<td>959</td>
</tr>
<tr>
<td>1971-2000</td>
<td>827</td>
</tr>
<tr>
<td>1981-2010</td>
<td>710</td>
</tr>
</tbody>
</table>

It is quite clear from Figure 8 that the number and duration of negative deviations have increased considerably especially since the 1980s. An unprecedented inflow-deficit was registered first between 1988 and 1995 for eight consecutive years, and after a short intermission between 2000 and 2009 for ten consecutive years.

We also analyzed the input side of the water budget equation from the standpoint of the ratio-changes within the input between the individual elements. The results of our calculations are demonstrated in Figure 9.
Figure 8. Deviation of the sums of yearly inflow from the 30-year (1971-200) mean.

Figure 9. Ratios of precipitation and inflow within the input in the water budget.

We determined that until the mid 1980s (for more than 60 years) inflow accounted for 60% while precipitation accounted for 40% of the input in the water budget. In the years after this period the ratio began to change – primarily due to
the significant decrease in the inflow to the lake. The proportion of the inflow gradually receded and the proportion of the precipitation respectively increased. In the first half of the 2000s the proportion of inflow dropped under 50% and precipitation accounted for more than 50% of all the input – this was the reversal of the previous period. After this as more precipitating years followed, the proportions of inflow and precipitation moved back towards the values which traditionally characterized an average water budget. This phenomenon directs our attention to the following: prolonged and unidirectional meteorological – and the resulting hydrological – extremes can temporarily cause drastic changes in the historically accepted proportions between the elements of the input side of the water budget.

For the purpose of combined assessment of inflow to the lake and precipitation on the catchment area we created Figure 10. We marked the years based on the combination of the above two parameters, separately marking the years between 2000 and 2011. The dashed lines separate the extreme high (90% exceeding probability) and the extreme low (10% exceeding probability) values in case of both precipitation and inflow. Years with values within this colored rectangle ‘bordered’ by these dashed lines can not be classified as extreme in terms of water balance even if there exist considerable differences between them. On the other hand for the years with values outside of the colored area – depending on

![Figure 10. Correlation between precipitation on the catchment area and inflow to the lake](image-url)
their exact location in this coordinate system – extreme status can be given regarding both of these parameters. It is a striking fact that in the 2000-2011 period 6 years are classified as extremely dry, extremely low inflow.

The only true exception is the year 2010 which was excessively precipitating. Even though that year was truly extreme in terms of precipitation, the same can not be said of inflow. The most probable reason for this is that a considerable portion of the water was taken up by the dried out catchment area to recover from the preceding consecutive years of low precipitation and restore some of the underground water supplies. Only the remaining portion of rainfall was converted into inflow that actually increased the water supply of the lake itself.

REFERENCES

12. VITUKI (2003), A Balaton vízpótlásának szükségessége: hidrológiai elemzések végzése. Témajelentés, tsz.: 721/1/6131-01, témafelelős: Varga György; Budapest
THE ANALYSIS OF THE SILTING PROCESS OF VĂRSUÑT RESERVOIR

OANA MOIGRÁDEAN

ABSTRACT. – The Analysis of the Silting Process of Vârsuñt Reservoir. The silting process of Vârsuñt reservoir has been monitored beginning with the year 1983. The successive hydro-topometric surveys done in 1983, 1985, 1989, 1991, 1995, 1997, 2002, 2009 and the resulting data were reported to the initial morphometric characteristics of the lake, for the period 1979 – 2009 and to the one obtained out of the following topographic surveys. The methodology consists in determining the evolution of the silting of the Vârsuñt reservoir by calculating the characteristic volumes: dead volume, available volume, flash flood protection volume, above overflow volume, attenuation volume, global volume and the global volume corresponding to the height of the dam. The period 1979-2009 notes a global silting volume in the reservoir of 7,852 million m³, representing 16,43% of the initial volume. Analysing the silting of the characteristic volumes in the mentioned period one can notice that in the first 12 years (1979-1991) the process was very intense, and considerably diminished in the last 18 years (1991-2009). The determination of the sediment volume reaching the reservoir was done by means of the solid discharge measured at Crasna hydrometric station between 1981-2009. The volume of sediments accumulated in the reservoir resulting from the difference between the volumes at a normal service level in 1979 and 2009 is of 5.71 million m³. The silting degree corresponding to this volume is of 26,5%, with an average annual silting rate of 0,59%.

Cuvinte cheie: suspended load, characteristic volumes, silting rate, silting degree

1. Introduction

Vârsuñt reservoir in situated in the western part of Sâlaj county, in the piedmont Depression of Crasna, overlapped in its turn to the eastern part of the Șimleu Basin (Fig. 1). It was built after closing up the Crasna River at approximately 1 km upstream of Vârsuñt village, 1 km downstream of the confluence of Crasna River with Mortâuña brook and at a distance of 96 km from the border with Hungary (Șerban, Gh., Mirisan, B, Câmpean, I., Selagea, H., 2010). Vârsuñt reservoir was operated in two stages: stage I in 1978 and stage II in 1979. It was built for flash flood attenuation on Crasna River, the drinking water supply of Zalau and Șimleu Silvaniei, sport fishing.

The reservoir is V shaped, with the Crasna branch 3 km long and 1.3 km wide and the Colițca branch 3 km long and 1.5 km wide.