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**HSAF**

Support to Operational  
Hydrology and Water  
Management

## **Validation of precipitation products over basins included in OVF modelling system**

Final Report

8 December 2017

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| <p>Final Report<br/>H_AVS16_01</p> | <p>Validation of precipitation products<br/>over basins included in OVF<br/>modelling system</p> | <p>The EUMETSAT<br/>Network of<br/>Satellite Application<br/>Facilities</p>  <p><b>HSAF</b><br/>Support to Operational<br/>Hydrology and Water<br/>Management</p> |
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## *1. INTRODUCTION*

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Operational forecasting of river flow has a basic role in handling many important issues like developing early warning of floods, prediction of low flow for navigation or water resources prediction for operating reservoirs. Continuously improved distributed operational hydrological models necessitate high resolution and quality data which in most of the cases cannot be provided only by ground measurements with sparse density.

H-SAF Hydrological Programme is focused on assessment of H-SAF products by validation, product evaluation and interfacing with hydrological models and tends to improve the products and their usability in operational hydrology in order to provide improved input data for hydrological models and support operational hydrology. H-SAF activities concern satellite products validation, implementation methodology and tools for better use of satellite products, incorporating available ground information to satisfy hydrological community with combined products having accuracy and resolution aligned with hydrological users' requirements. This approach aims to accomplish the added value of satellite derived products in operational streamflow forecasting through hydrological models.

Since integration of all available measurement data is a key requirement for providing high quality forecasts, this study aims to evaluate the integration of H-SAF precipitation products into an operatively used hydrological forecast model. Although many countries participate in it, HSAF Hydrological validation programme leaves many uncovered areas in Europe. Based on the OLSER forecast system with its domain including the Danube basin until the Drava mouth, this study gives the possibility to validate H-SAF precipitation products by introducing new test sites in Europe for validation.

## 2. MODEL DESCRIPTION

### 2.1. OLSER Model

General Directorate of Water Management (OVF) hosts Hungary's operative hydrological forecasting centre, Hungarian Hydrological Forecasting Service (HHFS). The Hydrological Simulation and Forecasting Model System (OLSER) used operatively in OVF has been developed at HHFS consisting of almost exclusively self-developed software packages. The OLSER conceptual model serves for simulations and forecasting of flow for medium and large drainage basins. At the moment HHFS operative modelling domain includes three main basins, namely Danube (until the Drava mouth – station Almjas, Croatia), Drava and Tisza basins.

In the course of a decade of continuous development and upgrading the forecasting system has grown into a complex tool containing snow accumulation and snowmelt, soil frost, effective rainfall, runoff, flood routing and backwater effect modules, extended with statistical error correction modules (Figure 2.1).

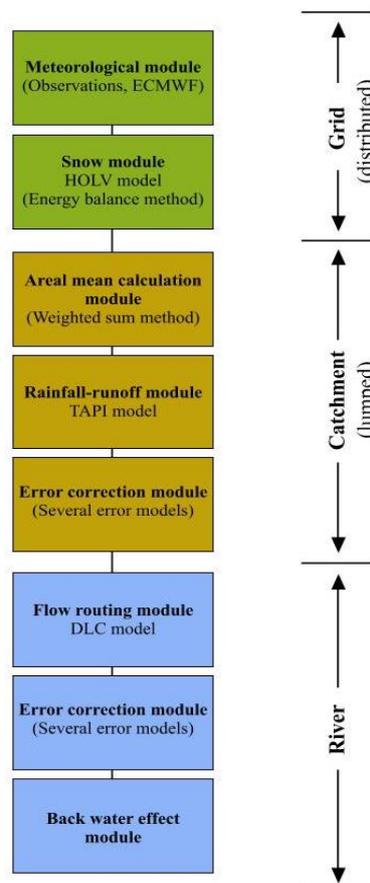


Figure 2.1 Functional modules of the OLSER forecasting system

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The OLSER functional modules are as follows:

- meteorological module takes into account meteorological observations and forecasts on a 0.1x0.1 degree resolution grid
- snow module handles all snow-related processes (it is based on the HOLV model performing snow package calculations for 33 sub-catchments on a 0.1x0.1 degree grid over the entire forecast domain)
- areal mean calculation module producing spatial averages which serve as meteorological input for all sub-catchments
- rainfall-runoff module (based on the TAPI rainfall-runoff model using API for its calculations)
- flow routing module (using the DLCM model)
- error correction module containing special algorithms developed to consider for example the patterns in hydropower plants' operation
- backwater effect module handles the interaction on a tributary flow and the receiving river

The forecasting system is in daily operation on the following sub-catchments: Danube above estuary of Inn, Inn, Traun, Enns, Vienna Basin, Morava, Rába-Répcse, Vág (Váh), Garam (Hron), Ipoly (Ipel'), Central Danube Valley, Zala and Balaton, Sió-Kapos-Sárviz, Upper Tisza Valley, Szamos (Someş), Kraszna (Crasna), Bodrog, Sajó (Slaná), Hernád (Hornád), Zagyva-Tarna, Central Tisza Valley, Körösök (Crişuri), Maros (Mureş), Mura (Mur), Upper Drava, Lower Drava. Some the above sub-catchments are further divided into smaller sub-basins (Figures 2.2 and 2.3). The average height of the sub-basins varies between around 180 and 1700 metres, while the average slope is between around 4 and 23 degrees, minimum multiannual mean areal precipitation amounts are around 600 mm, maximum is around 1600 mm. Thereby the OLSER model system with such a widely varying range of geographical characteristics on its domain and long-term development and operational background is a solid basis for validation purposes.

The system has 6-days lead time (with a time step of 6 hours), it is run daily, but in exceptional cases (e.g. serious flood situations) it can be run more frequently. In the operational use the model results are supervised and modified if needed by the expert hydrologist on duty. Forecasts are published and provided for all the public and domestic users involved in the field.

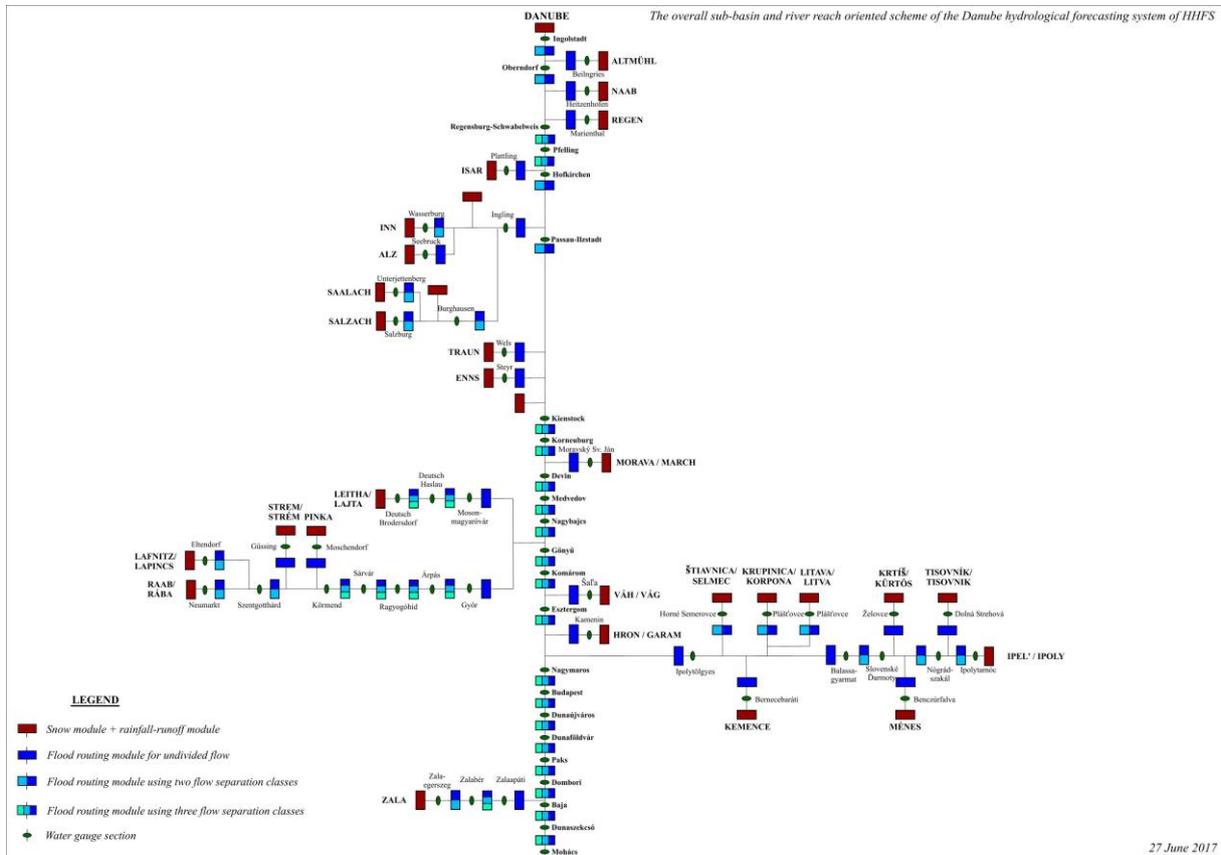


Figure 2.2 The overall sub-basin and river reach oriented scheme of the Danube river in OLSER forecasting system

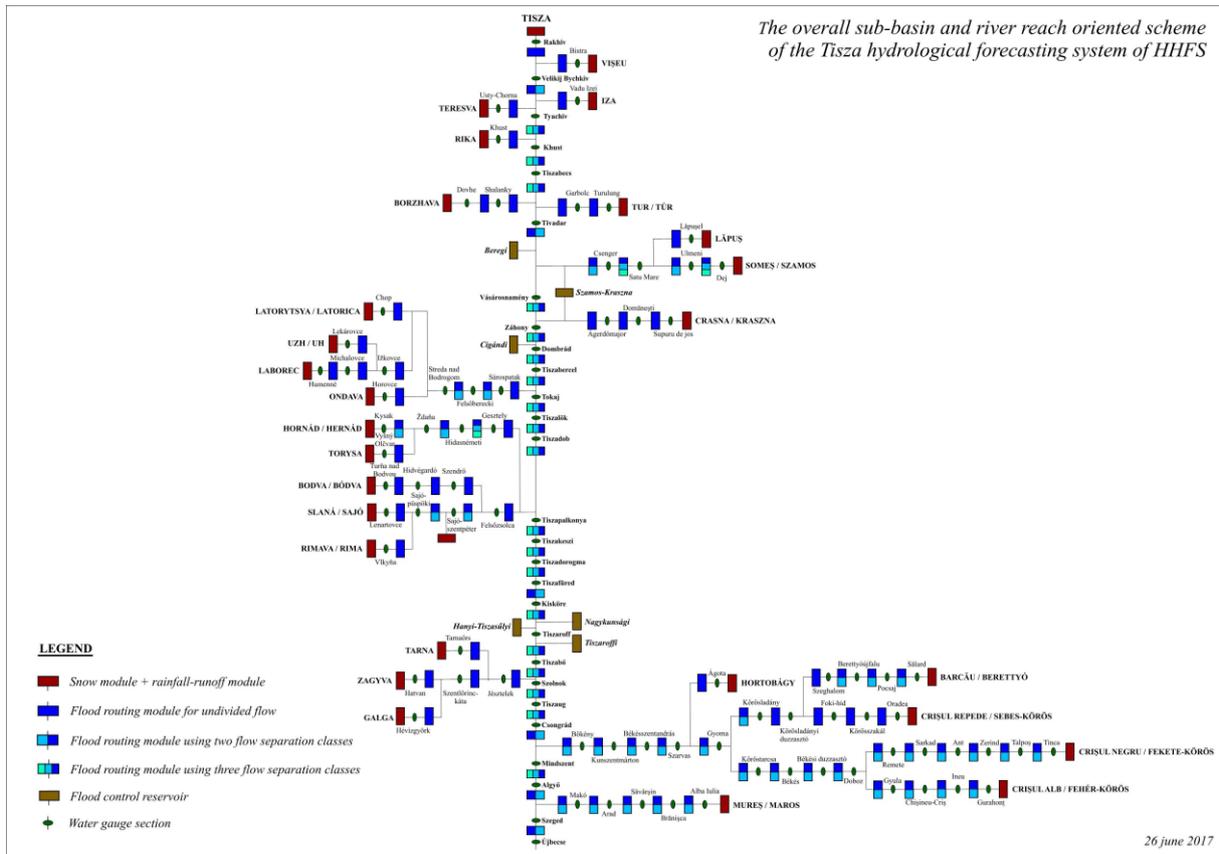


Figure 2.2 The overall sub-basin and river reach oriented scheme of the Tisza river in OLSER forecasting system

## *2.2. TAPI Rainfall-Runoff Model*

Runoff is one of the most complex processes within the hydrologic cycle. Certain part of the precipitation always evaporates or becomes intercepted by the vegetation canopy before it reaches the surface of the watershed. Interception may be significant, especially in summer over fully vegetated surfaces, thus it should not, in general, be neglected. Its magnitude is influenced mostly by canopy density and its wetness status. The former changes seasonally, the latter depends on prior precipitation events.

The remaining part of precipitation reaching the ground collects in micro- and macro-depressions of the surface, or partly runs off over it. As time goes on during a precipitation event, ever more micro-depressions become filled and so an increasing portion of the catchment takes part in contributing to runoff. A significant portion of the water reaching the generally pervious surface of the watershed seeps into the soil. The rate of infiltration at a certain location of given geologic, soil, slope and vegetation characteristics, will predominantly be influenced by the moisture content of the topsoil, and so directly, by antecedent precipitation conditions.

A significant part of the infiltrated water will contribute to interflow in the loose topsoil, driven mainly by topography. Interflow may be considerable especially in catchments with coniferous vegetation, where surface runoff may be negligible compared to the rate of interflow. Interflow is often considered as a cross-over between seepage and open-surface flow, and may be closer to the latter due to its generally high velocity and small residence time.

Some of the infiltrated water reaches the deep soil where it may still contribute to stream flow as unsaturated flow, or may recharge the ground water which eventually supplies the stream as its base flow. The rate of change in the base-flow process is typically slow – especially for larger rivers – due to potentially significant underground storage and characteristic low flow velocities in porous media.

This short description of runoff formation highlights the complex nature of the process, and points out the importance of the antecedent moisture status of the watershed besides the runoff-triggering precipitation event.

TAPI rainfall-runoff model was developed by experts at the Hungarian Hydrological Forecasting Service as a part of the OLSER forecast system. The model's name "TAPI" specifies the technique by which the actual soil moisture status is accounted for. The "API" part is an acronym for Antecedent Precipitation Index, while the "T" refers to the current method's similarity to the Tank Model structure developed by M. Sugawara.

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The model's main characteristics are presented below.

TAPI model is strongly related to the Hungarian Hydrological Forecasting Service's OLSER model, but it also can be used separately. In order to achieve good operational performance, TAPI was constructed as a basically lumped model, but certain calculations are carried out on a 0.1 x 0.1 degree grid of the basins before the actual model run. These calculation steps are listed below:

- interpolation of meteorological ground measurements on the above mentioned grid (based on different inverse distance coefficients)
- considering snow accumulation and melting processes (snow model)
- calculation of interception loss
- definition of potential evapotranspiration values.

Since the above calculation steps are not strictly part of the TAPI model, they will not be presented in details. The interpolation is based on the inverse distance method with different power values depending on the data type and also on actual the season, taking into consideration the orographic effects. The snow model calculates the energy balance of the snow cover and provides surface water income and soil condition (frost) data. Interception loss calculation is regulated by monthly changing parameters based on vegetation coverage and state of precipitation. Potential evapotranspiration is estimated using the Thornthwaite method.

Accordingly, input data for TAPI model are averaged gridded values of surface water income, soil state and potential evapotranspiration. Different (surface and subsurface) runoff processes are considered and transformed with the use of Discrete Linear Cascade Model (DLCM).

The runoff ratio can be defined as

$$\alpha_t = \frac{\sum (Q_i - Q_{0i})}{\sum u_i}$$

where:

$Q_i$  is the stream-flow rate at time  $i$  [ $m^3s^{-1}$ ].

$Q_{0i}$  is the base-flow rate at time  $i$  [ $m^3s^{-1}$ ].

$u_i$  is precipitation rate at time  $i$  [ $m^3s^{-1}$ ].

The above summations involve long time-series, thus the time-delay between precipitation and runoff is negligible. The base-flow rate can be obtained from multi-year stream flow records. It is possible to specify a summer base-flow rate, which may be several times larger than its otherwise regular value.

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This way base-flow contribution of glaciers in alpine watersheds (e.g. certain sub-catchments of the Upper Danube) can be accounted for.

The ratio of surface and shallow as well as deep subsurface flow changes seasonally and depends largely upon the moisture condition of the catchment, and so indirectly upon the antecedent precipitation condition.

Typically, spatial distribution of the soil moisture status of the watershed is not known even for research catchments, and the few available point-measurements are seldom representative of the whole watershed. For operational rainfall-runoff models such information is therefore available only indirectly, through the use of antecedent precipitation indices. Naturally, the more time elapsed since the last precipitation event, the less is its ensuing effect on the actual moisture condition of the watershed. The Antecedent Precipitation Index (API) reflects this mechanism by employing weights in decreasing order as one goes back in time as multipliers of the observed precipitation values. The weight function may typically be linear, parabolic, or exponential in time. TAPI employs the following weighting

$$API_i = \sum_{t=0}^n P_{i-t} e^{-at}$$

where:

$P_i$  is the precipitation sum at time  $i$ .

$n$  is the total number of values considered in the weighting process.

$a$  is a model parameter, setting the speed at which the weights decline backward in time.

The value of  $n$  is set by the term in the series that contributes less than 0.05 to the sum. This way the last  $n$  time-increments influence the catchment's runoff.

Seasonally changing evaporation and interception losses are estimated by the following expressions

$$V_i = D[1 + \sin(A\pi)];$$

$$A = \frac{304.5 - i}{183}$$

where:

$V_i$  is the loss at the  $i^{\text{th}}$  day of the year [mm];

$D$  is the maximum value of the loss within the year [mm].

After obtaining the value of API and  $V_i$ , and calculating the value of effective precipitation as the difference between precipitation and losses, the ratio ( $\alpha_1$ ) of surface and subsurface runoff can be estimated as

$$\alpha_1 = 1 - \sqrt{\frac{CAPKUL}{CAPMAX}}$$

$$CAPKUL = CAPMAX - API \quad \text{if } CAPMAX > API$$

$$\alpha_1 = 1$$

otherwise, where CAPMAX is the API value that belongs to a fully saturated soil. Once reaching this stage, all effective precipitation runs off on the surface.

When the top soil is frozen, the value of  $\alpha_1$  is increased. A soil frozen to a depth of 5 cm results in infiltration rates reduced by about 80%, while the same of 10 cm causes effective precipitation to form surface runoff entirely.

A certain part ( $\alpha_b$ ) of the infiltrated water will be lost for runoff, another portion ( $\alpha_a$ ) of what is left will form subsurface runoff while the remaining becomes interflow. This way TAPI separates total runoff into four pathways:

1) surface runoff:

$$Q_{fei} = P_i \alpha_i \alpha_1$$

2) interflow:

$$Q_{fki} = P_i \alpha_i (1 - \alpha_1)(1 - \alpha_b)(1 - \alpha_a)$$

3) subsurface runoff:

$$Q_{fai} = P_i \alpha_i (1 - \alpha_1)(1 - \alpha_b) \alpha_a$$

4) base flow, its estimation being explained above.

Once the different ratios are specified, the amounts must be estimated. Routing of water in all three pathways above is performed with the help of serially connected linear reservoirs (forming a cascade)

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in each path. This way one obtains three parallel cascades, with parameters  $n_i$  and  $k_i$  ( $i = 1,2,3$ ) for each one, a discrete cascade model is employed.

The following model parameters of TAPI need optimization:  $n_1$ ,  $k_1$ ,  $k_2$ ,  $k_3$ ,  $a$ , CAPMAX,  $\alpha_a$ , and  $\alpha_b$ .

### 3. TEST BASINS

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At the moment the OLSER operative forecasting system domain includes three main basins, namely Danube (until the Drava mouth – station Almjas, Croatia), Drava and Tisza basins.

As we mentioned in the previous section, the above domain is divided into the following main sub-basins: Danube above estuary of Inn, Inn, Traun, Enns, Vienna Basin, Morava, Rába-Répcse, Vág (Váh), Garam (Hron), Ipoly (Ipeľ), Central Danube Valley, Zala and Balaton, Sió-Kapos-Sárvíz, Upper Tisza Valley, Szamos (Someş), Kraszna (Crasna), Bodrog, Sajó (Slaná), Hernád (Hornád), Zagyva-Tarna, Central Tisza Valley, Körösök (Crişuri), Maros (Mureş), Mura (Mur), Upper Drava, Lower Drava. Some the above sub-catchments are further divided into smaller sub-basins. The average height of the sub-basins varies between around 180 and 1700 metres, while the average slope is between around 4 and 23 degrees, minimum multiannual mean areal precipitation amounts are around 600 mm, maximum is around 1600 mm.

Out of these numerous sub-basins 3 were considered to be included in this study. On Figure 3.1 their location is shown presenting their position within the whole Danube catchment. The selected sub-basins are:

- Rába (Raab) basin
- Sajó (Slaná) basin
- Upper Tisza basin

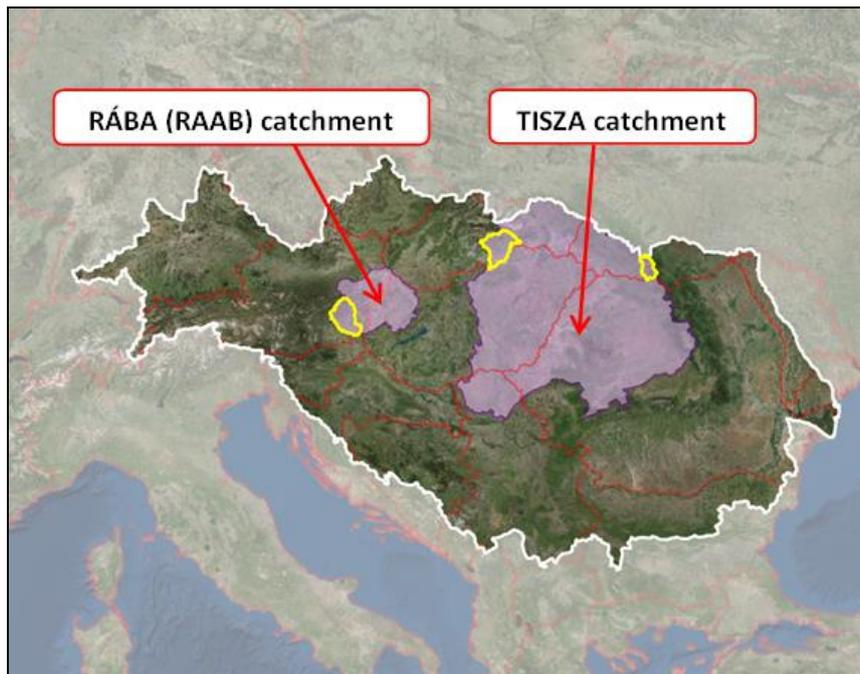


Figure 3.1 Location of the studied sub-basins within the Danube catchment

### 3.1. *Rába (Raab) basin*

Rába (Raab) basin is located in southeast of Austria and west of Hungary, it is right tributary of the Danube. The total basin area is 10 113 km<sup>2</sup>, the river is 398 km long and originates from some kilometres east of Bruck an der Mur, below Heubodenhöhe Hill and it flows into the Mosoni-Danube in north-western Hungary, in the city of Győr.

The river reaches Hungary at Szentgotthárd, which is the outflow section of the studied sub-basin.

The area of this sub-basin is about 3100 km<sup>2</sup> and the length of the river to Szentgotthárd gauge is about 128 km. Upstream of this section 3 major tributaries flow to River Rába (Raab): Weizbach, Rabnitzbach and Lafnitz.

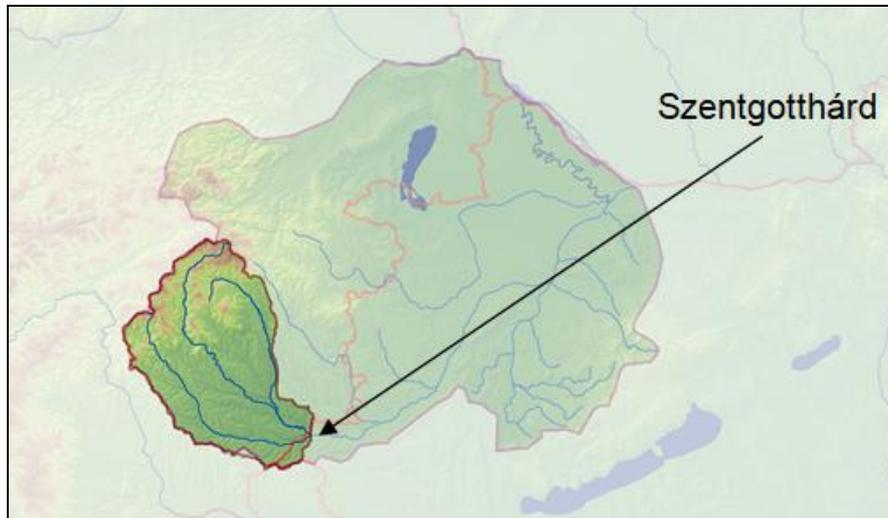


Figure 3.2 Location of the studied Rába (Raab) sub-basin above Szentgotthárd gauge

#### 3.1.1. *Landform features, elevation*

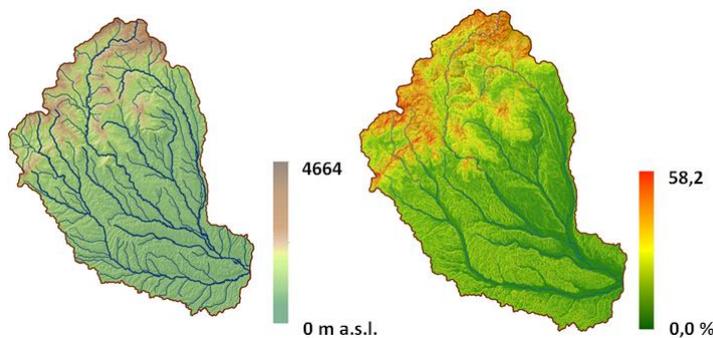
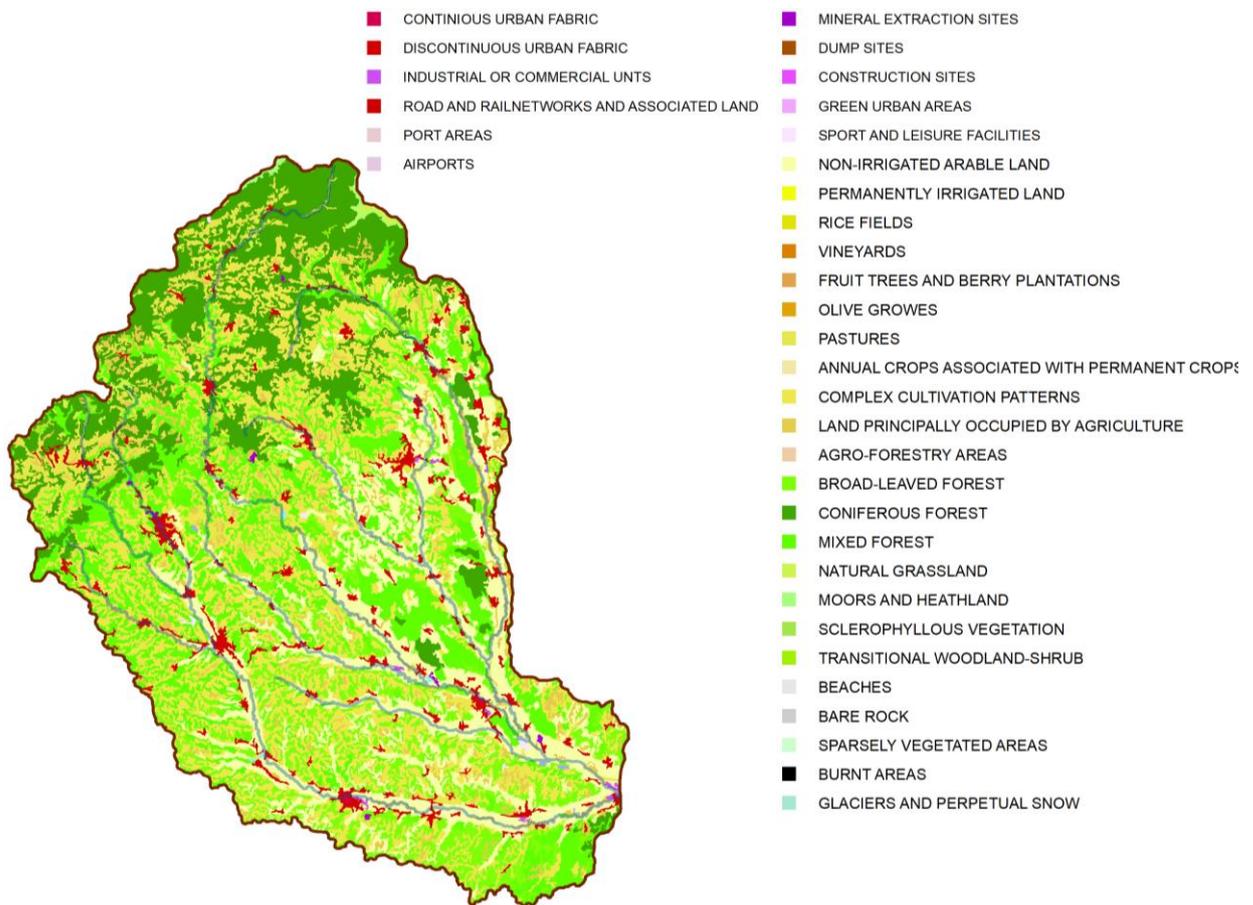


Figure 3.3 Digital Terrain Model (on the left) and slope (on the right)

There are two main morphological areas in the sub-basin: the upper mountainous region with steep and narrow valleys, and the lower region, where the average slope is below 25%, but the slope of the riverbed is still around 0,001.

The highest elevation of the sub-basin is 1772 meters above sea level, and the lowest elevation is 215 meters above sea level.

### 3.1.2. Land use and urbanization



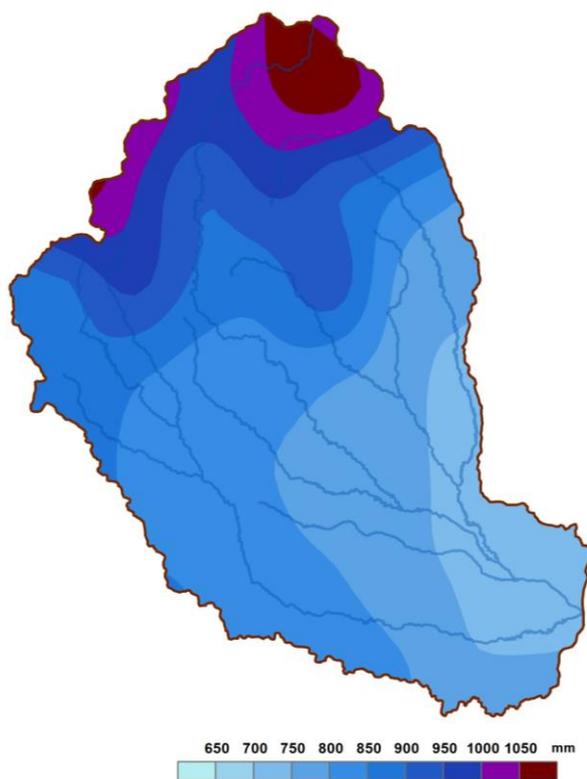
**Figure 4 Land Cover derived from Corine database**

More than 50% of the sub-basin is covered by arable land, about 30% of forest, 7% of meadows, pastures, reeds and 2% of urban areas, the largest cities are Feldbach, St. Ruprecht an der Raab, Waltersdorf, Dobersdorf

### 3.1.3. Hydrological and meteorological description

**Table 3.1 Hydrometeorological description of Rába (Raab) catchment above Szentgotthárd**

| Hydrological description (1987-2016) |       |       |       |       |       |       |       |       |       |       |       |       |       |
|--------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Mean:                                | I     | II    | III   | IV    | V     | VI    | VII   | VIII  | IX    | X     | XI    | XII   | Year  |
| Precipitation (mm)                   | 30,0  | 33,8  | 45,1  | 53,3  | 88,7  | 113,7 | 113,3 | 108,7 | 96,5  | 65,7  | 56,7  | 40,4  | 846,0 |
| Temperature (°C)                     | -1,5  | -0,2  | 3,4   | 7,9   | 12,6  | 15,7  | 17,9  | 17,7  | 13,5  | 8,8   | 3,5   | -0,6  | 8,3   |
| Runoff [m <sup>3</sup> /s]           | 16,48 | 21,67 | 26,15 | 24,66 | 23,12 | 26,16 | 23,81 | 24,55 | 26,06 | 19,39 | 20,26 | 19,47 | 22,64 |



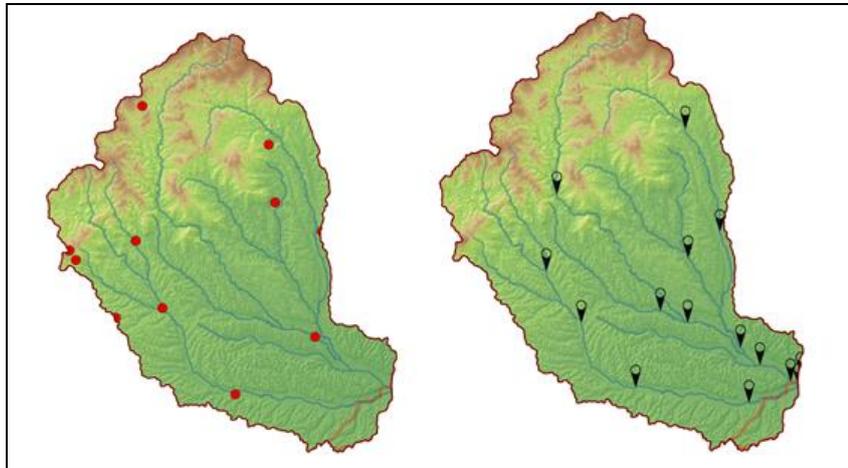
**Figure 3.5 Multi-year mean precipitation**

In Table 3.1 are reported the catchment mean values of precipitation, temperature and runoff for the multiyear period 1987-2016. Runoff values refer to Szentgotthárd gauging station.

The flow of the river is balanced, almost constant. Wet period or snow melting can lead to flooding.

The north-eastern part of the river basin is the wettest region.

### 3.1.4. Facilities



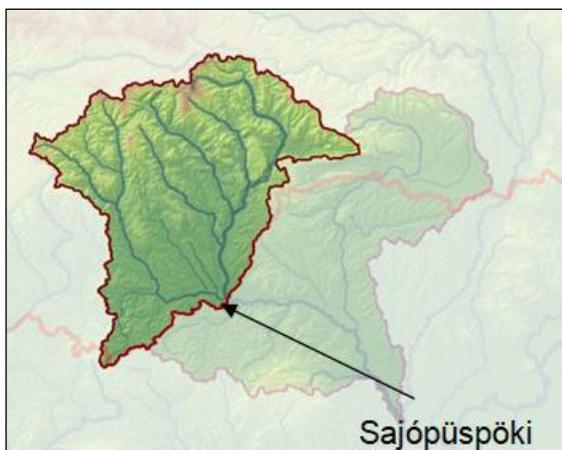
**Figure 3.6** Meteorological (on the left) and hydrological (on the right) network

There are 11 meteorological stations on the catchment, they are part of the Zentralanstalt für Meteorologie und Geodynamik (ZAMG) network. The following data are available: precipitation, temperature and wind speed, the temporal resolution of the observations is 1 hour.

The water level data is provided by two organizations. On one hand the Hydrographischer Dienst Burgenland (River Lafnitz), on the other hand the Wasser Wirtschaft Land Steiermark. Both organizations provide hourly data.

## 3.2. Sajó (Slaná) basin

The River Sajó (Slaná) is one of the largest rivers in Eastern Slovakia and North-eastern Hungary, it is a significant tributary of the Tisza.



**Figure 3.7.** Sajó (Slaná) sub-basin above Sajópüspöki gauge

The total basin area is 12 708 km<sup>2</sup>, the river is 223 km long and its source is in the Stolica Mountains range of the Slovak Ore Mountains, at about 1300 meters above sea level. It flows into the Tisza river near Tiszaújváros.

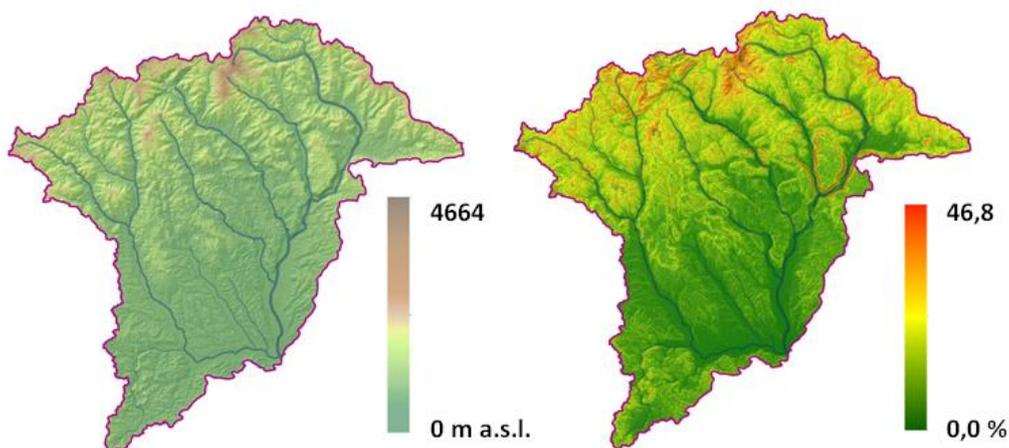
The river reaches Hungary at Sajópüspöki, which is the outflow section of the studied sub-basin.

The area of this sub-basin is about 3200 km<sup>2</sup> and the length of the river to Sajópüspöki gauge is about 98 km. In this section 4 major tributaries flows to Sajó (Slaná) river: Stitnik, Muran, Turiec and Rimava.

### 3.2.1. Landform features, elevation

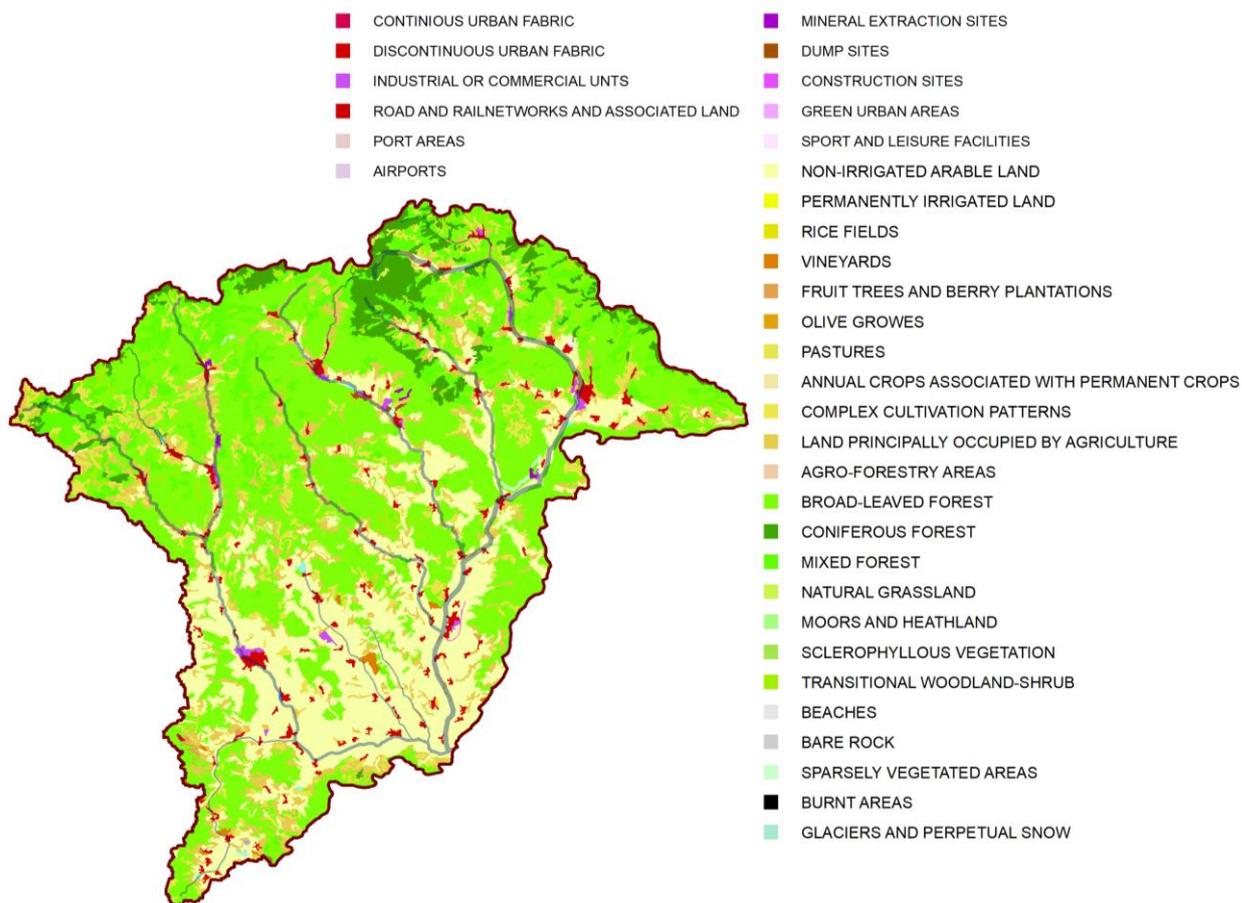
It starts near the peak called Stolica (1476 m a.s.l.), then quickly runs down from the hillside with densely populated pine trees. The second main morphological region is a mild part with an average slope of about 5-10 %

The elevation of the catchment ranges from 148 m a.s.l. to 1471 m a.s.l. with an average height of about 460 m a.s.l.



**Figure 3.8 Digital Terrain Model (on the left) and slope (on the right)**

### 3.2.2. Landuse and urbanization



**Figure 3.9 Land Cover derived from Corine project**

The majority of the sub-basin is covered by forest, urban areas are concentrated along main rivers. The largest cities are Rožňava, Revúca, Topoľčany and Rimavská Sobota.

### 3.2.3. Hydrological and meteorological description

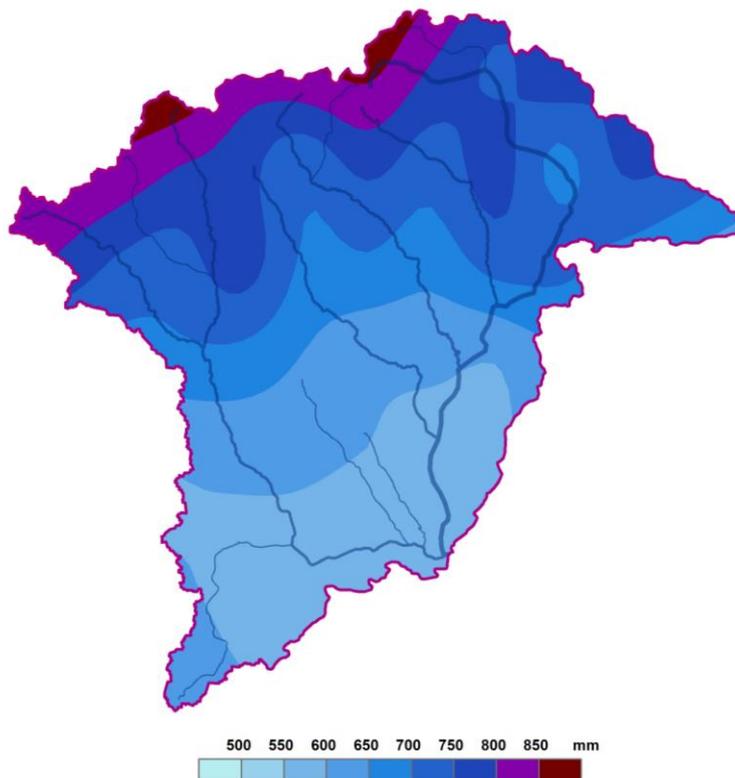
**Table 3.2 Hydrometeorological description of Sajó (Slaná) basin above Sajópüspöki**

| Hydrological description (1987-2016) |      |      |      |      |      |      |      |      |      |      |      |      |       |
|--------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|-------|
| Mean:                                | I    | II   | III  | IV   | V    | VI   | VII  | VIII | IX   | X    | XI   | XII  | Year  |
| Precipitation (mm)                   | 33,7 | 34,4 | 37,9 | 51,5 | 80,8 | 88,9 | 92,3 | 68,6 | 57,9 | 53,0 | 50,7 | 38,4 | 688,1 |

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|                               |       |       |       |       |       |       |       |      |       |       |       |       |       |
|-------------------------------|-------|-------|-------|-------|-------|-------|-------|------|-------|-------|-------|-------|-------|
| Temperature<br>(°C)           | -2,6  | -1,1  | 3,0   | 8,3   | 13,0  | 16,3  | 18,4  | 18,1 | 13,7  | 8,8   | 3,4   | -1,7  | 8,2   |
| Runoff<br>[m <sup>3</sup> /s] | 17,59 | 22,08 | 33,26 | 34,45 | 26,22 | 24,27 | 17,09 | 14,9 | 11,83 | 12,52 | 15,69 | 17,65 | 20,61 |

In Table 3.2 the sub-basin mean values of precipitation, temperature and runoff for the multiyear period 1987-2016 are presented. Runoff values refer to Sajópüspöki gauging station.



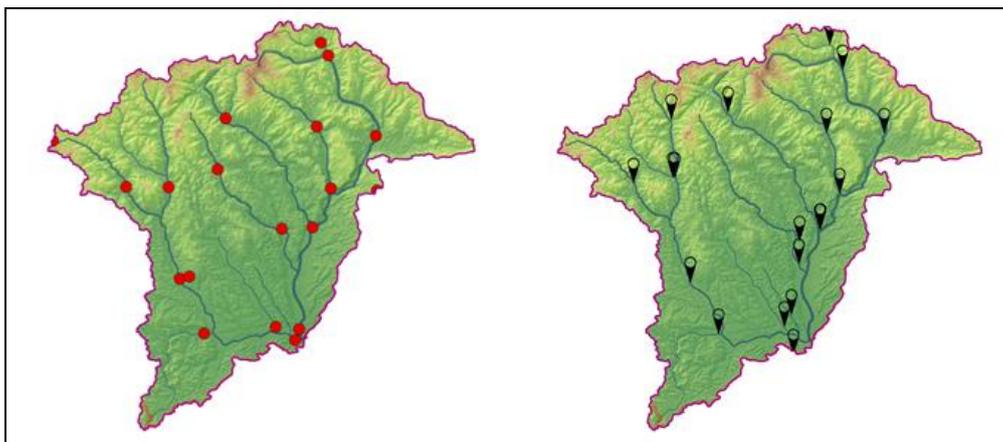
In this area significant snow accumulation is possible, therefore flash floods from snow melting occur more often than usual (the highest mean discharges are in March and April).

The basin is situated under the permanent snow-line. About 70% of the snow falls in the December-February period.

**Figure 3.10 Multi-year mean precipitation**

### 3.2.4. Facilities

Both hydrological and meteorological (only raingauges) stations are handled by the Slovak Hydrometeorological Institute (SHMU). The temporal resolution of the data is 1 hour.



*Figure 3.11 Meteorological (on the left) and hydrological (on the right) network*

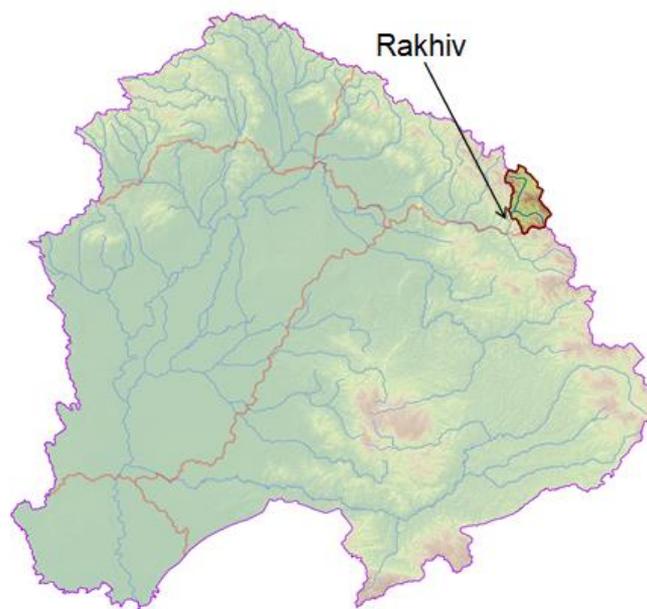
### *3.3. Upper Tisza basin*

River Tisza is one of the main rivers in Central Europe and an important tributary of the Danube.

The total basin area is about 157 000 km<sup>2</sup>, the river is 962 km long.

The river has two sources. The Black Tisza and the White Tisza are 53 km away from each other.

These two river reaches merge about 1.5 km from Rakhiv gauging station. The actual source of the Tisza is considered to be the source of the Black Tisza. It flows into the Danube at Titel.



*Figure 3.12 Tisza sub-basin above Rakhiv gauging station*

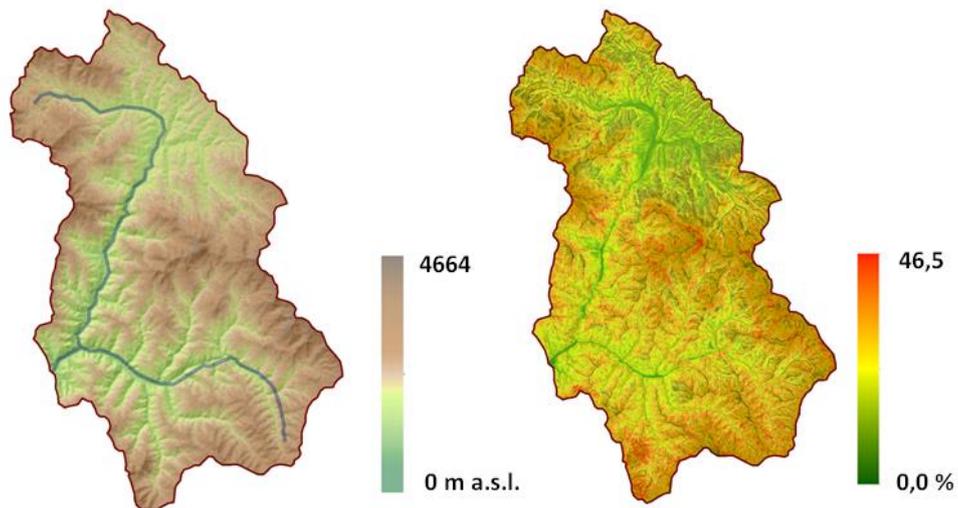
The studied domain is the sub-basin upstream of Rakhiv.

The area of this sub-basin is about 1100 km<sup>2</sup> and the length of the river to Rakhiv gauge is about 98 km.

### ***3.3.1. Landform features, elevation***

The average elevation of this sub-basin of the mountainous Upper-Tisza is about 1070 m a.s.l. (minimum: 434 m a.s.l., maximum: 2037 m a.s.l.).

The rived bed is relatively deep. The average slope of the basin is above 30%.



***Figure 3.13 Digital Terrain Model (on the left) and slope (on the right)***

### 3.3.2. Hydrological and meteorological description

**Table 3.3 Hydrometeorological description of Tisza catchment above Rakhiv**

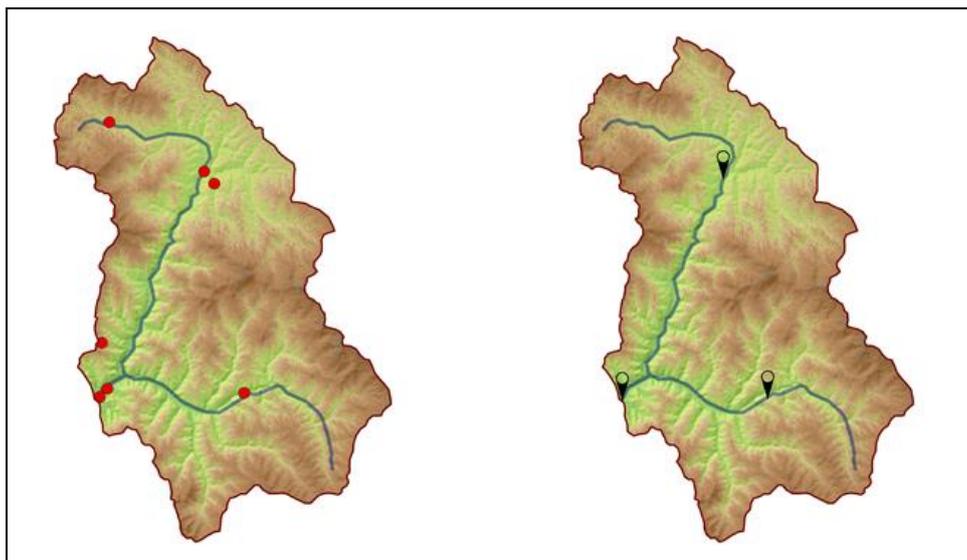
| Hydrological description (1987-2016) |       |       |       |       |      |       |       |       |       |       |       |      |        |
|--------------------------------------|-------|-------|-------|-------|------|-------|-------|-------|-------|-------|-------|------|--------|
| Mean:                                | I     | II    | III   | IV    | V    | VI    | VII   | VIII  | IX    | X     | XI    | XII  | Year   |
| Precipitation (mm)                   | 67,6  | 67,2  | 86,1  | 79,8  | 97,7 | 110,5 | 116,1 | 86,3  | 103,2 | 87,3  | 91,7  | 95,5 | 1090,5 |
| Temperature (°C)                     | -3,9  | -2,6  | 1,4   | 7,1   | 12,0 | 15,3  | 17,2  | 16,9  | 13,5  | 7,6   | 2,3   | -2,9 | 7,0    |
| Runoff [m <sup>3</sup> /s]           | 14,57 | 16,62 | 17,22 | 24,52 | 22,5 | 14,87 | 24,4  | 26,12 | 17,02 | 27,89 | 15,11 | 14,1 | 19,76  |

In Table 3.3 are reported the catchment mean values of precipitation, temperature and runoff for the period 1987-2016. Runoff values refer to Rakhiv gauging station.

In the Tisza valley large floods can develop at any time of the year.

Rapid streams running down on steep hills reach the river valley very quickly and are often accumulated there.

### 3.3.3. Facilities



**Figure 3.14 Meteorological (on the left) and hydrological (on the right) network**

|                                    |  |   |
|------------------------------------|--|---|
| <p>Final Report<br/>H_AVS16_01</p> | <p>Validation of precipitation products<br/>over basins included in OVF<br/>modelling system</p> | <p>The EUMETSAT<br/>Network of<br/>Satellite Application<br/>Facilities</p>  |
|------------------------------------|--|---|

Both hydrological and meteorological data are available in the form of SYNOP telegram.

Transcarpathian Regional Center for Hydrometeorology provides water level, precipitation and temperature data.

The measuring network, which has been established and operated by the Hungarian and Transcarpathian hydrometeorological directorates and equipped with a telemetry service provide hourly data.

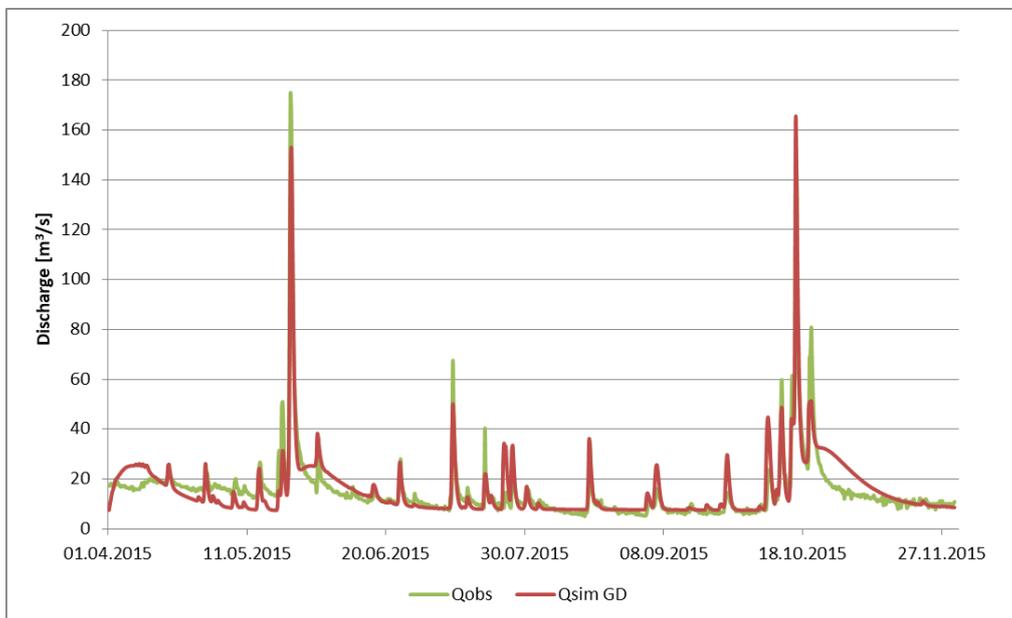
## 4. CALIBRATION RESULTS

### 4.1. Rába (Raab) basin

Calibration for Szentgotthárd station was carried for the period: 01. April 2015 – 30. November 2015. In the selected calibration period two flood waves occurred on the river. The calibration was based on ground observed precipitation data and provided satisfying result, since the highest discharge for both flood peaks were simulated with a reasonable accuracy. After the first period's uncertainty due to the initial soil moisture value, water regime in both summer and autumn period was suitably captured by the model. Table 4.1 contains statistical scores of the calibration and on Figure 4.1 observed and simulated hydrographs are shown.

**Table 4.1 Calibration results for Rába (Raab) basin at Szentgotthárd station**

| Statistical Score | MaxAE  | MAE   | RMSE  | R     | N - S |
|-------------------|--------|-------|-------|-------|-------|
| Value             | 35,500 | 3,800 | 5,833 | 0,914 | 0,824 |



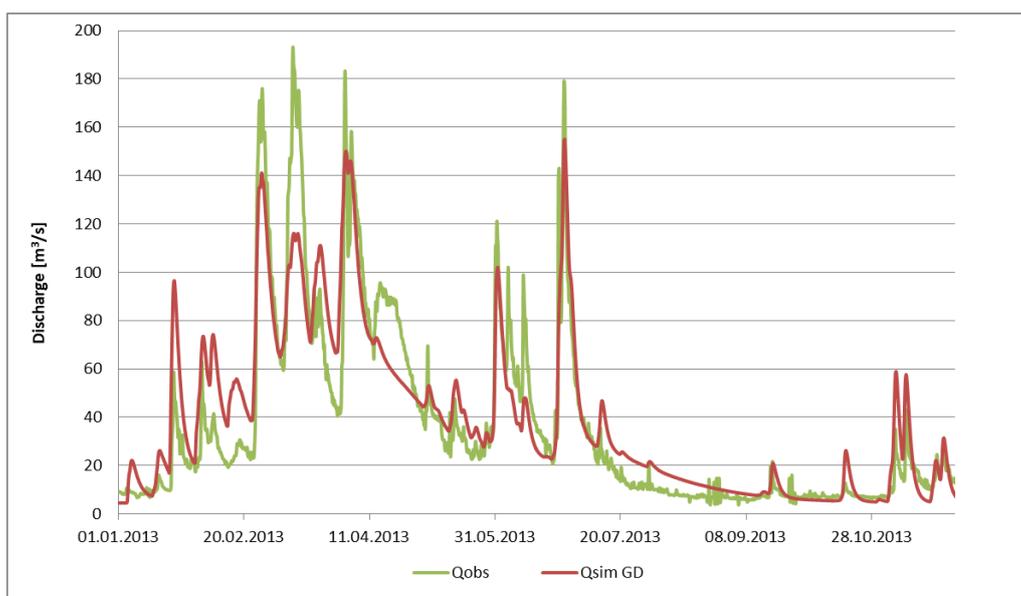
**Figure 4.1 Six-hour runoff hydrographs simulated with observed ground data (QsimGD) and observed runoff (Qobs) at gauge Szentgotthárd/Rába (Raab) in calibration period April – November 2015**

## 4.2. Sajó (Slaná) basin

Calibration for Sajópüspöki station was carried for the period: 01. January 2013 – 31. October 2013. The results are considered appropriate. The differences in late winter-early spring period are caused by the major uncertainty in the temporal evolution of the snow melting processes. Peak flows after the winter period are slightly underestimated. Table 4.2 contains statistical scores of the calibration and on Figure 4.2 observed and simulated hydrographs are shown.

**Table 4.2 Calibration results for Sajó (Slaná) basin at Sajópüspöki station**

| Statistical Score | MaxAE  | MAE    | RMSE   | R     | N - S |
|-------------------|--------|--------|--------|-------|-------|
| Value             | 78,000 | 11,156 | 16,082 | 0,913 | 0,828 |



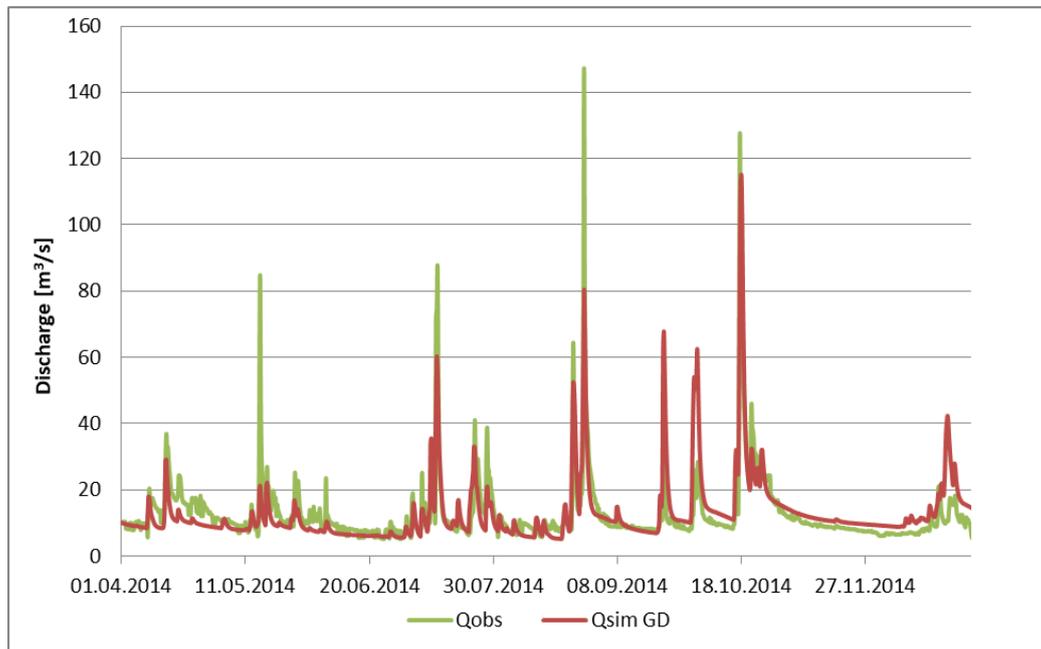
**Figure 4.2 Six-hour runoff hydrographs simulated with observed ground data (QsimGD) and observed runoff (Qobs) at gauge Sajópüspöki/Sajó (Slaná) in calibration period January – October 2013**

### 4.3. Upper Tisza basin

The selected Rakhiv station is located at the confluence of the Black and White Tisza. The results of calibration performed for Upper Tisza basin for the period 01. April 2014 – 30. November 2014 are slightly less satisfactory than for the other two basins. The reason behind this is probably the relatively small size of the basin comparing to the 6-hourly time step of the model. Although the variability of the precipitation intensity within one time step can have a significant effect at this spatial scale, it cannot be considered at the temporal resolution of the model. Table 4.3 contains statistical scores of the calibration and on Figure 4.3 observed and simulated hydrographs are shown.

**Table 4.3 Calibration results for Upper Tisza basin at Rakhiv station**

| Statistical Score | MaxAE  | MAE   | RMSE  | R     | N - S |
|-------------------|--------|-------|-------|-------|-------|
| Value             | 66,900 | 4,004 | 6,996 | 0,779 | 0,550 |



**Figure 4.3 Six-hour runoff hydrographs simulated with observed ground data (QsimGD) and observed runoff (Qobs) at gauge Rakhiv/Upper Tisza in calibration period April – November 2014**

Based on the calibration results for the three selected basins, it can be stated that Hydrological Simulation and Forecasting Model System (OLSER) describes runoff conditions' temporal

|                            |   |  |
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evolution with suitable accuracy and it is applicable for the analysis of the HSAF precipitation data planned in this study.

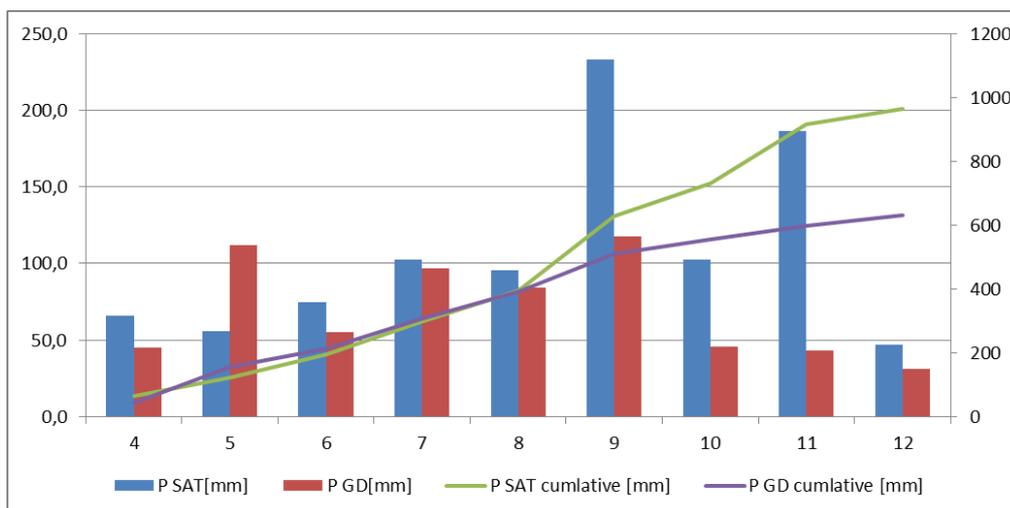
## 5. VALIDATION RESULTS AND CONCLUSIONS

After calibration OLSER system was used to test H05 precipitation product. Since the model time step is 6 hour, H05 precipitation sum product with the same time step was chosen for validation. After decoding binary grib files and transformation to text format, the original grid values were interpolated to the 0.1 degree resolution domain of OLSER model, finally areal means were calculated by arithmetic mean for the three selected basins. The model itself was also prepared for the test runs.

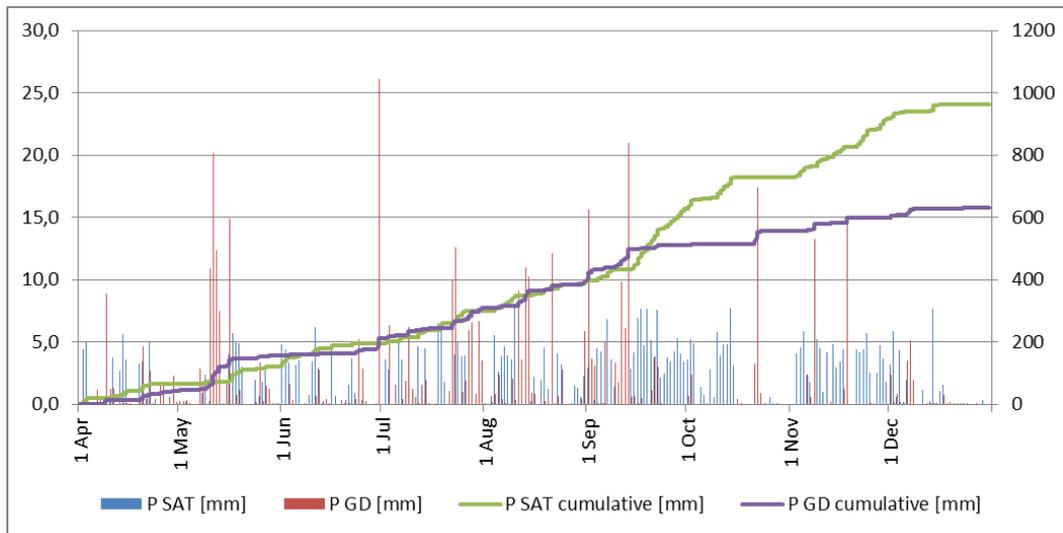
In this section, validation results are presented for the three selected test basins.

### 5.1. Rába (Raab) basin

The period 01 April 2014 – 31 December 2014 was chosen as validation period for Rába (Raab) basin. Considering monthly rainfall totals, according to Figure 5.1, in about one third of the examined period significant difference occurred between ground measurements and satellite data. However, having a closer look on the detailed precipitation time series (on Figure 5.2) it becomes clear that differences are present also at a smaller time step, too, and actually during the whole period. Ground measurements typically indicate less precipitation events with higher values, satellite data, on the other hand show more and longer precipitation events, with smaller values (between 3-7 mm). In several cases when according to ground measurements significant rainfall took place, satellite data indicate none or very small values.

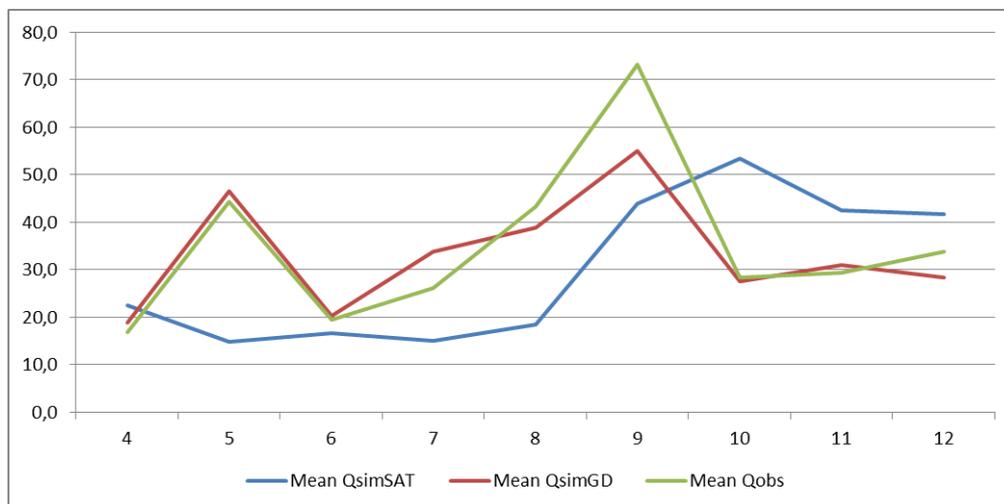


**Figure 5.1 Monthly (bars) and accumulated monthly precipitation sums (lines) of river basin Rába (Raab) with H05 data and observed ground data in validation period April – December 2014**

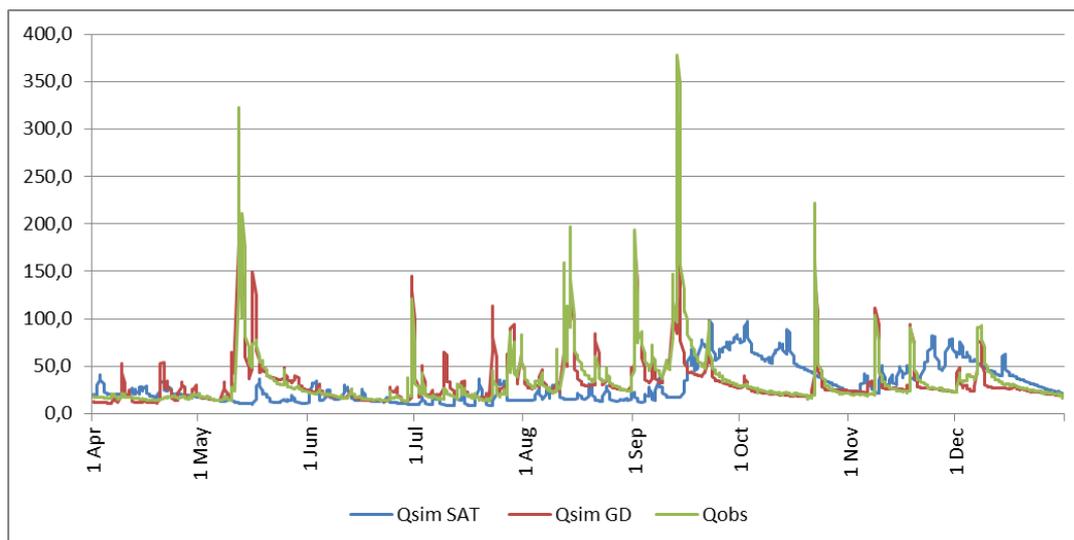


**Figure 5.2 Six-hour (bars) and accumulated six-hour precipitation sums (lines) of river basin Rába (Raab) with H05 data and observed ground data in validation period April – December 2014**

When comparing the runoff simulations (Figures 5.3 and 5.4), results are in accordance with the above mentioned conclusions, namely, significant flood waves don't appear on the satellite based simulations, instead a big number of small waves are shown in the results.



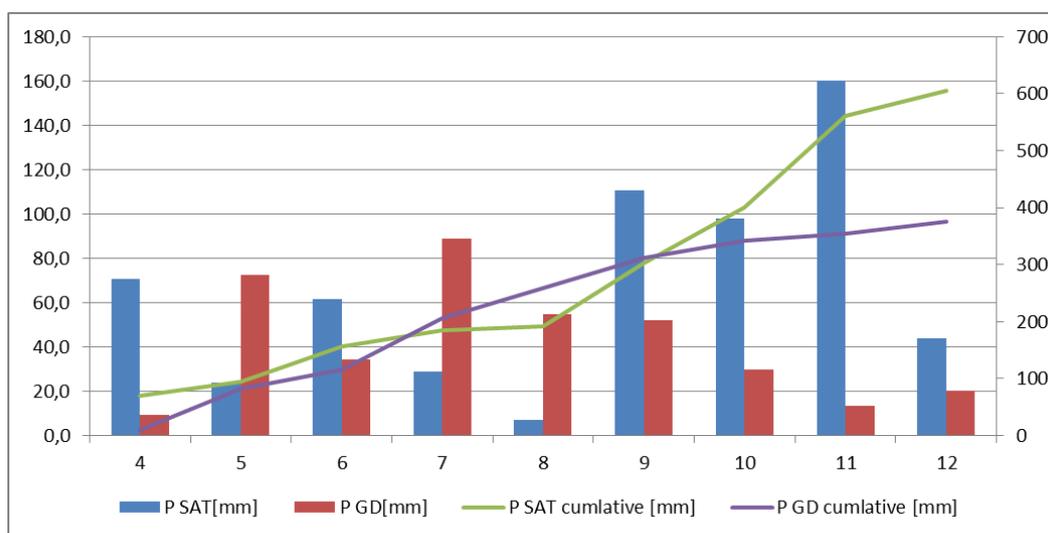
**Figure 5.3 Monthly mean runoff simulated with H05 (QsimSAT) and with observed ground data (QsimGD) and observed runoff (Qobs) at gauge Szentgotthárd/Rába (Raab) in validation period April – December 2014**



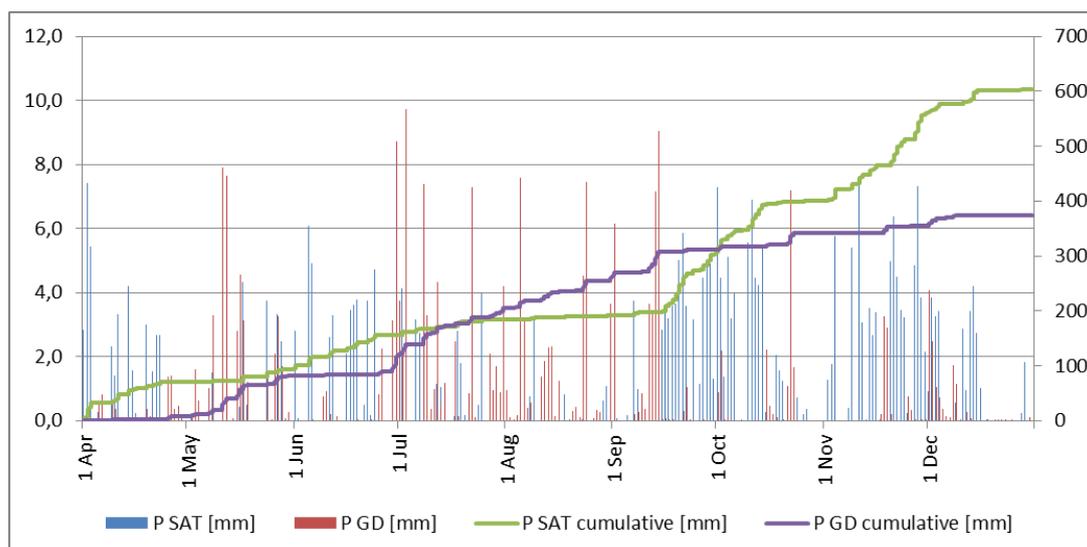
**Figure 5.4 Six-hour runoff hydrographs simulated with H05 (QsimSAT) and with observed ground data (QsimGD) and observed runoff (Qobs) at gauge Szentgotthárd/Rába (Raab) in validation period April – December 2014**

## 5.2. Sajó (Slaná) basin

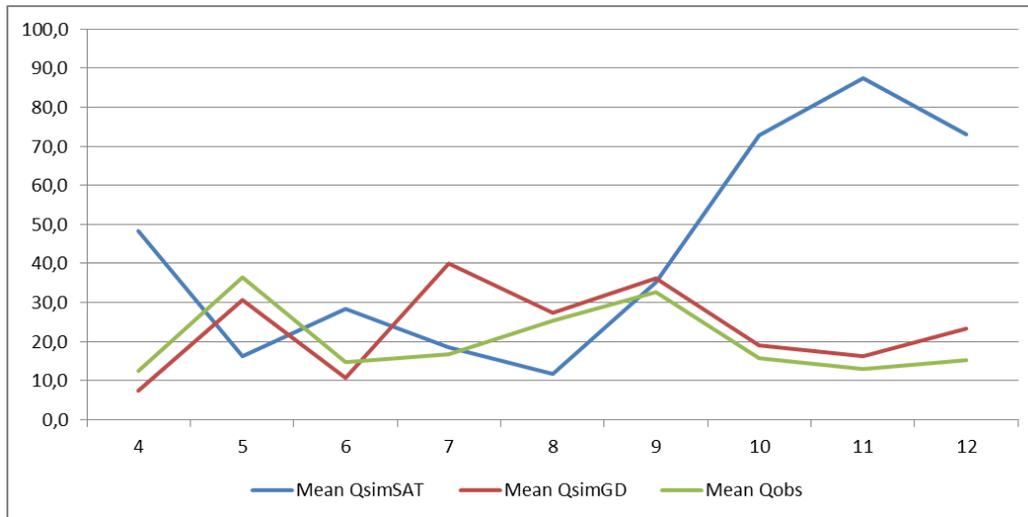
The period 01 April 2014 – 31 December 2014 was chosen as validation period for Sajó (Slaná) basin. Test results regarding monthly rainfall totals on Sajó (Slaná) basin similarly show big differences between ground measurements and satellite derived data. These differences are higher than 100% in almost every month (Figure 5.5). The precipitation time series (Figure 5.6) underline the severe underestimation during the summer months which are followed by a significant overestimation in the autumn.



**Figure 5.5 Monthly (bars) and accumulated monthly precipitation sums (lines) of river basin Sajó (Slaná) with H05 data and observed ground data in validation period April – December 2014**

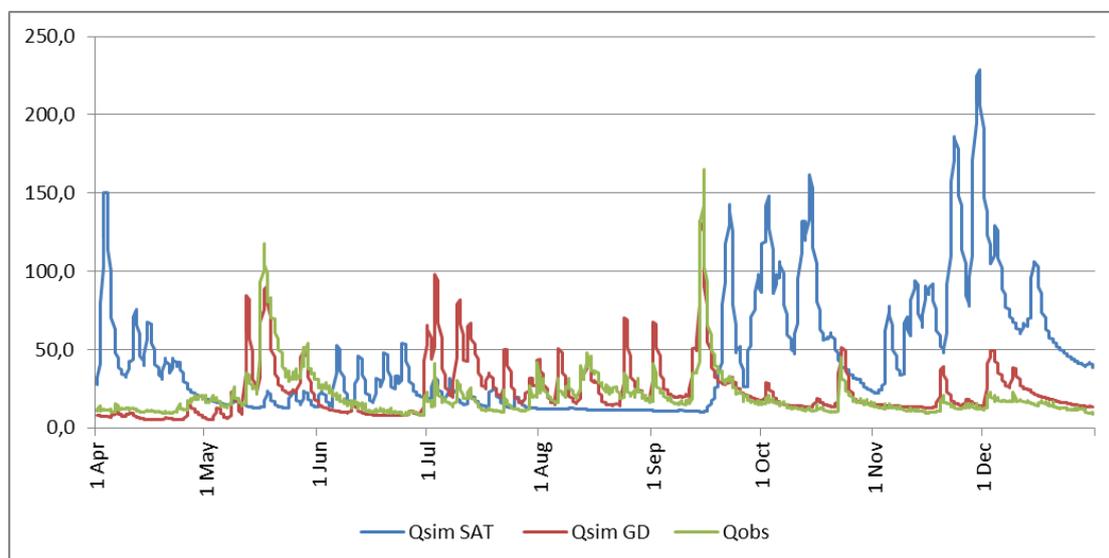


**Figure 5.6 Six-hour (bars) and accumulated six-hour precipitation sums (lines) of river basin Sajó (Slaná) with H05 data and observed ground data in validation period April – December 2014**



**Figure 5.7 Monthly mean runoff simulated with H05 (QsimSAT) and with observed ground data (QsimGD) and observed runoff (Qobs) at gauge Sajópüspöki/ Sajó (Slaná) in validation period April – December 2014**

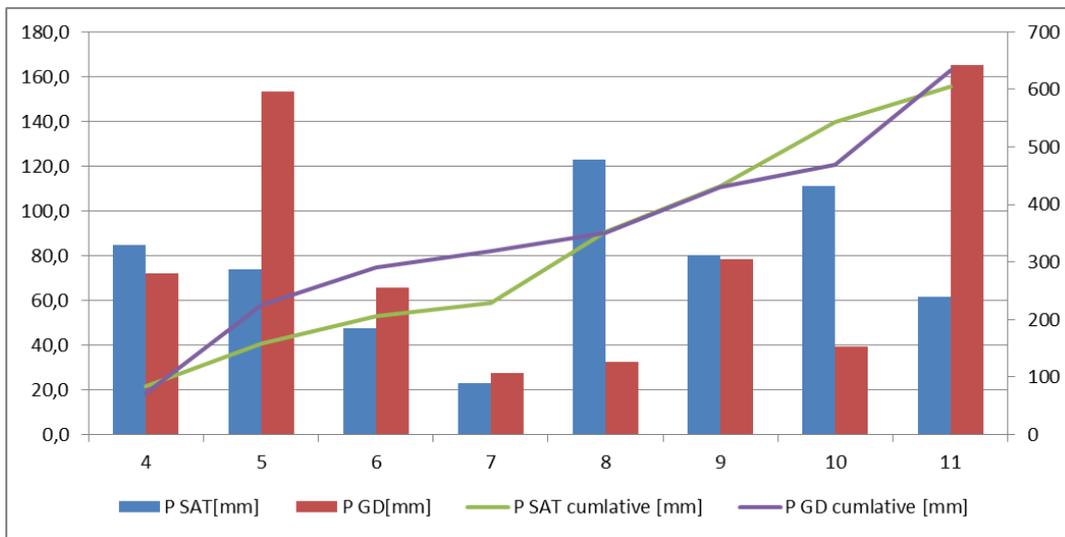
Consequently, Figure 5.8 shows that H05 driven runoff data simulation time series are very different from the observed runoff values and from the simulations based on ground measurements.



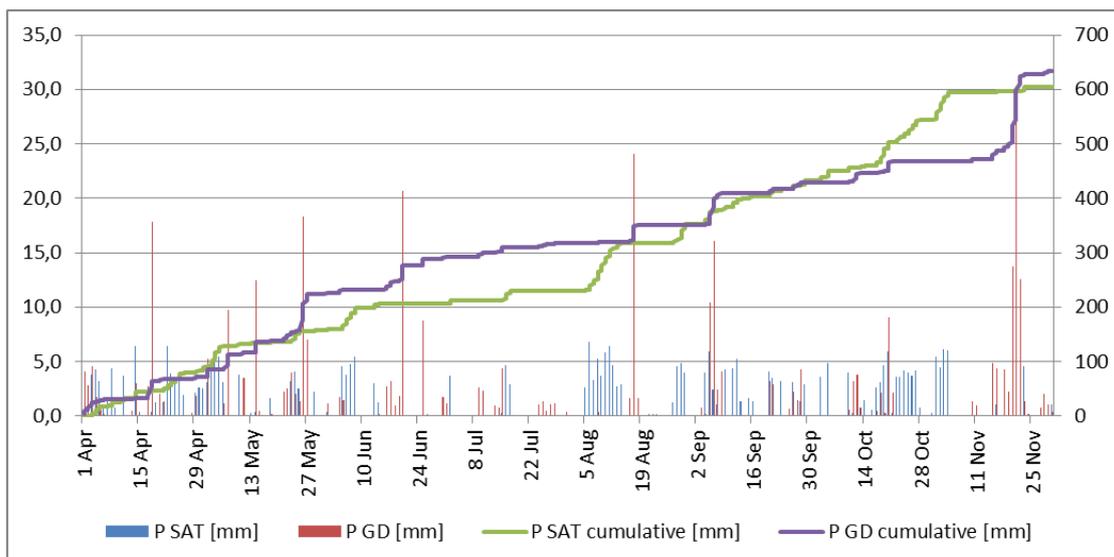
**Figure 5.8 Six-hour runoff hydrographs simulated with H05 (QsimSAT) and with observed ground data (QsimGD) and observed runoff (Qobs) at gauge Sajópüspöki/ Sajó (Slaná) in validation period April – December 2014**

### 5.3. Upper Tisza basin

The period 01 April 2014 – 30 November 2015 was chosen as validation period for Upper Tisza basin. In case of Upper Tisza basin, monthly rainfall totals show significant differences between the two data sources in four months: in two cases the ground measurements, in the other two cases the H05 data were much higher than the other (Figure 5.9). Similarly to the other two test basins, ground measurements typically indicate less precipitation events with higher values, satellite data, on the other hand show more and longer precipitation events, with smaller values (Figure 5.10).

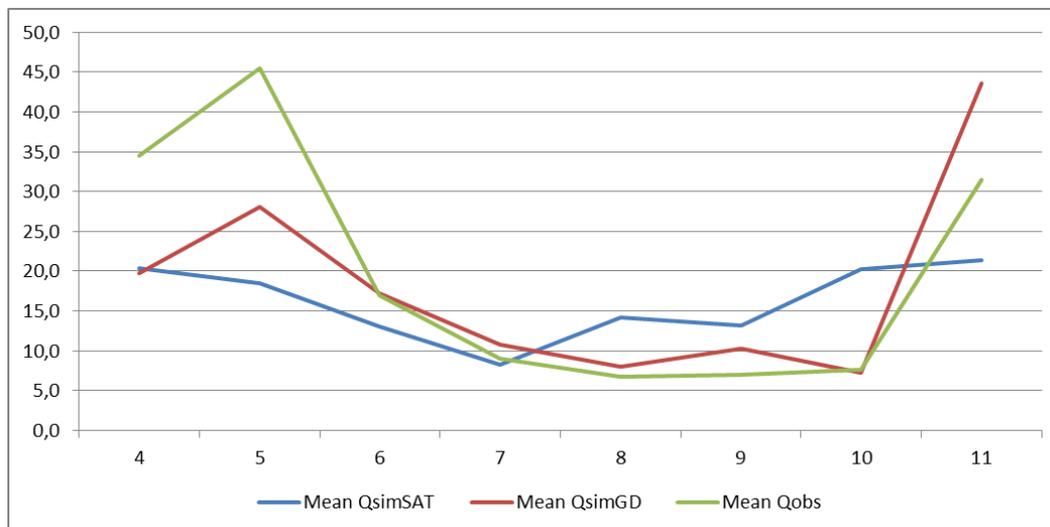


**Figure 5.9 Monthly (bars) and accumulated monthly precipitation sums (lines) of river basin Upper Tisza with H05 data and observed ground data in validation period April – November 2015**

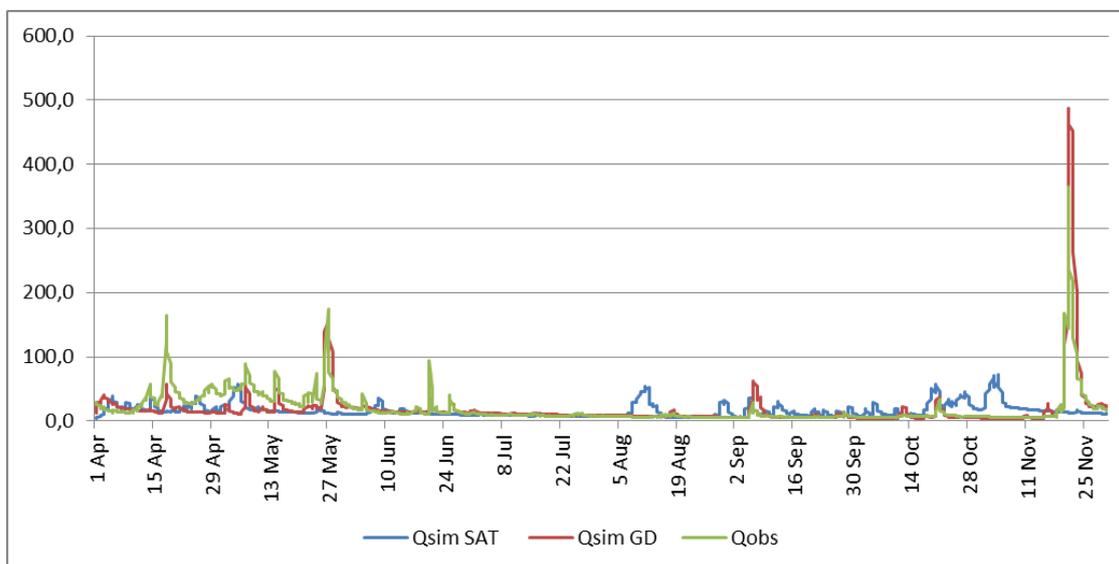


**Figure 5.10 Six-hour (bars) and accumulated six-hour precipitation sums (lines) of river basin Upper Tisza with H05 data and observed ground data in validation period April – November 2015**

In the validation period one significant flood wave occurred in the autumn, this flood peak doesn't appear in the H05 driven simulation runoff data. Beside this, during the long low water period, differences are not significant (Figure 5.12).



**Figure 5.11 Monthly mean runoff simulated with H05 (QsimSAT) and with observed ground data (QsimGD) and observed runoff (Qobs) at gauge Rakhiv/ Upper Tisza in validation period April – November 2015**



**Figure 5.12 Six-hour runoff hydrographs simulated with H05 (QsimSAT) and with observed ground data (QsimGD) and observed runoff (Qobs) at gauge Rakhiv/ Upper Tisza in validation period April – November 2015**

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Based on the above results, the following conclusions can be drawn:

- Daily flow variability was successfully simulated in the validation periods for all three basins using ground measurement precipitation data
- Significant differences both in time and magnitude between ground measurement and satellite precipitation data caused huge differences in flow simulations and in some cases lead to complete failure in runoff simulation based on H05 precipitation data.
- For all three validations ground measurements typically indicated less precipitation events with higher values, H05 precipitation data, on the other hand showed more and longer precipitation events, with smaller values, especially during the autumn.