Automatic Flood Prediction Using Rainfall Runoff Model in Moravian-Silesian Region

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***Abstract*—**Rainfall runoff models play important role in hydrological predictions. However, the model is only one part of the process for creation of flood prediction. The aim of this paper is to show the process of successful prediction for flood event (May 15 – May 18 2014). Prediction was performed by rainfall runoff model HEC–HMS, one of the models computed within Floreon+ system. The paper briefly evaluates the results of automatic hydrologic prediction on the river Olše catchment and its gages Český Těšín and Věřňovice.

***Keywords*—**Flood, HEC-HMS, Prediction, Rainfall – Runoff.

I. Introduction

FLOODS are the most common natural disaster in the Czech Republic. Floods directive of European Union defines flood as temporary covering by water of land not normally covered by water [11]. There are a lot of attempts to understand, manage and predict the mechanism of floods in the Czech Republic. Nowadays, mainly floods predictions are point of view for local researchers but the biggest issue is in traditional prediction approaches focused only on the main rivers. Czech Republic with dense river network must take into account influences of tributaries and not only main rivers. One of the possible approaches how to resolve this issue is to use rainfall runoff model (R-R) for prediction. A lot of scientist and their organizations use R-R models for predicting, e.g. HBV model was used for flood forecasting in Sweden [9] or HEC–HMS in Ethiopia [8]. Some of them create flood prediction systems in order to group all information in one place. It is a practical way how to inform public about upcoming flood event. The Iowa Flood Information System (IFIS) [5] and Web-based flood forecasting system (WFFS) [1] are good examples of such systems.

Rainfall-Runoff models still play important role in hydrological predictions. Generally, rainfall runoff model describes the rainfall runoff relations of a catchment and its main product is the surface runoff hydrograph [6]. More precisely, the model transforms rainfall into runoff [10]. Rainfall runoff models are often used as a tool for a wide range of task such as modelling of flood events, monitoring of water levels during different water condition or they are used as a flood prediction tool [7]. In case of flood predictions R-R models are very practical because they are even useful in the catchments with lack of input data. However, sufficient accuracy and quantity of data must be preserved because uncertainties in input data have influence on results. Precise flood prediction reduces the risk due to flood and can save people and their property.

The purpose of this paper is to show successful prediction of flood event (May 15 to May 18 2014). Prediction was carried out by R-R model HEC–HMS (USACE). The model is run within Floreon+ system [13], [14] which is a platform for integration and operation of monitoring, modelling, prediction and decision support for disaster management mainly in the Moravian-Silesian region (Czech Republic). Floreon+ is developed and maintained by the researchers at the VSB – Technical University of Ostrava. The main thematic area of the project is hydrologic modelling and prediction. The system focuses on acquisition and analysis of relevant data in real time and application of prediction algorithms with this data. The system is built as a cascade of rainfall runoff and hydrodynamic models. Floreon+ uses HEC-HMS and Math1D (developed by VSB) for modelling rainfall runoff processes and HEC-RAS (USACE) and MIKE 11 (DHI) for modelling hydrodynamic processes. Whole cascade runs fully automatically each hour and the regime of computation is based on the principle of 5 days of modelling and 2 days prediction. In this paper the principle is expressed as a “computational run window (CRW)”.

II. Study Area and Input Data

Complete R-R modelling was carried out on the Olše catchment (mainly for gages of Věřňovice and Český Těšín). The river is found in the north-east of the Czech Republic. Geologically, model domain of Floreon+ is composed of crystalline (Czech Massif; western part of domain) and flysch (Carpathian flysch, eastern part of domain) catchments. Hydrological response of western catchments is (mostly due to their geology) quite complicated and the models of these catchments are still the object of their parameterization refinement. Thus we chose one of the flysch catchment for the presentation of successful automatic hydrologic prediction results.

A major part of the Olše River basin is situated in the north eastern part of the Moravian-Silesian Region, whereas the rest of the basin area occupies part of southern Poland. Numerically expressed, the total basin area takes up 1,118 km^2, out of which 479 km^2 is in Poland. Along a substantial part of its length (24.6 km in total), the river makes up Czech-

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Polish state border. The total river length is 99 km, out of which 16 km in the territory of Poland. Its major tributary is the Stonávka River with the Těrlicko dam.

In our case (because we used SCS-CN method), input data as an important part of R-R modelling can be divided into two categories: (a) topographic data and (b) data for describing rainfall runoff process. Topographic data include just input DEM, whereas rainfall runoff data include e.g. roughness coefficients, hydrographs, CN numbers and precipitations (real/predicted). Description of hydraulic structures (e.g. dams) situated in the study area belong to the same group.

The input DEM in this study was created using photogrammetry method in 2010. The resolution of the DEM was 10 m, therefore it can be considered as appropriate for R-R modelling. Information about CN was obtained from raster with the resolution of 20 m. Other important data as description of hydraulic structures and real precipitations measurements were obtained from local state companies such as Odra catchment enterprise. Crucial factor for accurate simulations are predicted data (in this case precipitations). These data were provided by Medard meteorological model (developed by Institute of Computer Science, Academy of Sciences of the Czech Republic) and their structure were raster with resolution 9 km.

The method SCS-CN (Soil Conservation Service) was chosen for determining the amount of direct runoff from a rainfall [2], [4]. SCS-CN method provides precise results and it does not need a lot of different data sets. Basically, SCS-CN method needs besides precipitations only curve numbers as an input data. Curve number is an empirical parameter which is based on hydrologic soil group, land use and hydrologic condition. The range of CN in our study was from 30 to 98. Basic equation of the method is [3]:

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \quad (1)$$

where, P = rainfall; I_a = initial abstraction ($I_a = 0.2S$); S = soil moisture retention ($S = \frac{1000}{CN} - 10$); Q = runoff.

For the transformation of a precipitation to the runoff, Clark unit hydrograph was used and baseflow was solved using recession method.

III. Conditions for a Flood Event Occurrence

In the middle of May 2014 after a few-month drought characterised by minimum precipitation, the Czech Republic experienced an influx of cold air from the north related to atmospheric low pressure above Poland and Slovakia. The weather was cold and afternoon temperatures mostly failed to exceed 13°C. Except for low temperatures, there were heavy rains. Most precipitation was measured in the northern Moravia and Silesia. Critical situation was reported on water gage Český Těšín (river Olše), where water level reached 580 cm what was historical maximum. Average discharge in Český Těšín is 13.6 m^3/s in this period of year, but after heavy rains discharge 292 m^3/s was reached. Precipitation situation is depicted on radar image (Fig. 1) and on image from prediction model ALADIN (Fig. 2).

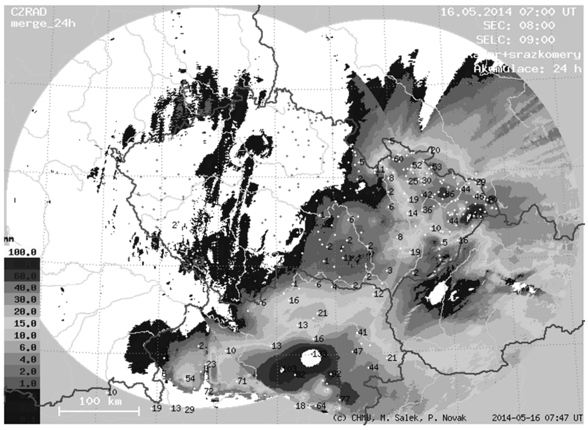

Fig. 1 Radar precipitation image for Czech Republic (date: 16.5.2014) [15]

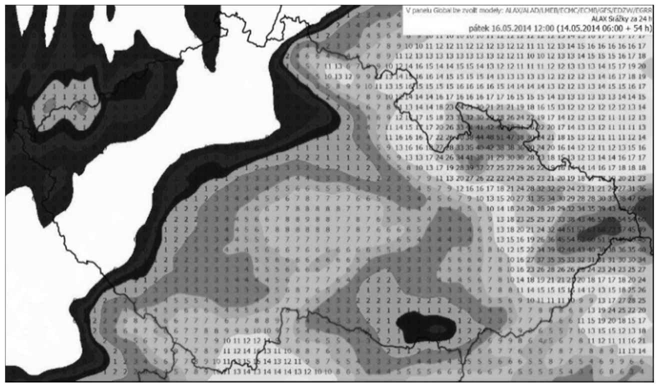

Fig. 2 Precipitation forecast (model ALADIN 16.5.14) [15]

IV. Results

The results and its evaluation are demonstrated on the river Olše catchment and the water gages Český Těšín and Věřňovice located within the catchment. Český Těšín is the Czech-Polish border town with about 25 thousand of residents. Český Těšín lies in the middle part of the catchment and the gage is located at the 41st upstream kilometer of the river. Area of the catchment above the gage is 384.6 km^2. Average annual water level at the gage is 154 cm, average annual discharge is 7.43 m^3/s. Water gage Věřňovice is an outlet gage of the whole catchment. It is located 7.5 km from the confluence of the river Olše with the Odra River and 4.5 km northwest from the town of Bohumín with approx. 22 thousand residents. Area of the catchment above the gage is 1075.6 km^2. Average annual water level at the gage is 105 cm, average annual discharge is 15.4 m^3/s. The values of extreme discharges and water levels are depicted in the Table I.

The evaluated rainfall runoff episode is discussed in the chapter III and the short description of Floreon+ system is presented in the chapter I. The evaluation of results illustrates the progress of the model outputs depending on the precipitation input changes and the shift of the computation run window in time. Precipitation prediction was available up from 15th May 2014 4PM, more than 1 day after the causal rainfall beginning.

TABLE I
FLOOD ACTIVITY DEGREES (FAD) AND RECURRENCE DISCHARGES (Q_N)

FAD	Český Těšín		Věřňovice	
	H (cm)	Q (m^3/s)	H (cm)	Q (m^3/s)
1	280	108	370	188
2	330	168	500	317
3	400	267	560	413

Q_N (m^3/s) →	Q_1	Q_5	Q_{10}	Q_{50}	Q_{100}
Český Těšín →	110	249	323	525	626
Věřňovice →	182	399	512	819	970

Upper part of the catchment (above Český Těšín gage) responded to the precipitation episode by the sharp, slightly asymmetric hydrograph with the steep rising limb and milder (but still relatively steep) falling limb. Rising phase of runoff lasted 1.5 day, falling phase 3 day. Peak discharge (16th May 2014 5AM) raised to 292 m^3/s. That was 25 m^3/s above FAD3 (flood activity degree) value, 43 m^3/s above Q_5 (5-year recurrence discharge) value and 31 m^3/s below Q_{10}. Hydrograph at the catchment outlet (Věřňovice gage) was relatively sharp as well, but it was nearly symmetrical compared with the upper gage hydrograph (Český Těšín). Rising phase of runoff lasted 2.5 day, falling phase for about 3 days. Peak discharge raised to 330 m^3/s (16th May 2014 1PM). That was 13 m^3/s above FAD 2 value and 69 m^3/s below Q_5. It is obvious that the majority of the runoff was formed in the upper part of the catchment above the Český Těšín gage. Runoff contribution of intercatchment below this gage was minimal. For both hydrographs see the Figs. 3 and 4.

Figs. 3 and 4 illustrate the time progress of the model inputs (observed and predicted precipitation) and the outputs (simulated and predicted discharge) for both intercatchments. In the first model computation run (*simulation = 10th May 2014 4PM →* ***15th May 2014 4PM*** *→ 17th May 2014 4PM = prediction*) model results for Český Těšín gage relatively reliably captured the trend of the initial growth of discharge. In prediction part of computation run window (CRW) model distinctly underestimated the peak discharge (163 m^3/s 16th May 2014 3AM). In the run following 4 hours later, but still with the same predicted precipitation input data (***15th May 2014 4PM***), model still distinctly underestimated peak discharge (203 m^3/s 16th May 2014 2AM). Peak discharge was predicted slightly below FAD2 value, in fact it reached slightly over FAD3 thereafter. However, with increasing time and simulations above real precipitation data model outputs gradually improved in prediction part of CRW as well. Next 4 hours later (***16th May 2014 0AM***) new predicted precipitation data set was available and then the model relatively reliably predicted the absolute value of peak discharge (264 m^3/s 16th May 2014 1AM), just only 3 m^3/s below FAD3 value. Predicted decrease of the runoff (falling limb) was overestimated in all of 3 illustrated computation runs. But the further shift of the CRW to the simulations rather above observed than predicted precipitation data results to the better and better good-of-fitness of falling limb of the observed and simulated/predicted hydrographs. Unfortunately it also resulted to the slight overestimating of the peak discharge. The best good-of-fitness of observed and modeled hydrographs was achieved in the computation runs between 17th May 2014 0AM and 19th May 2014 12AM, approximately 4 to 6 days after the beginning of rainfall runoff episode and therefore mostly or completely within simulation part of computation run window.

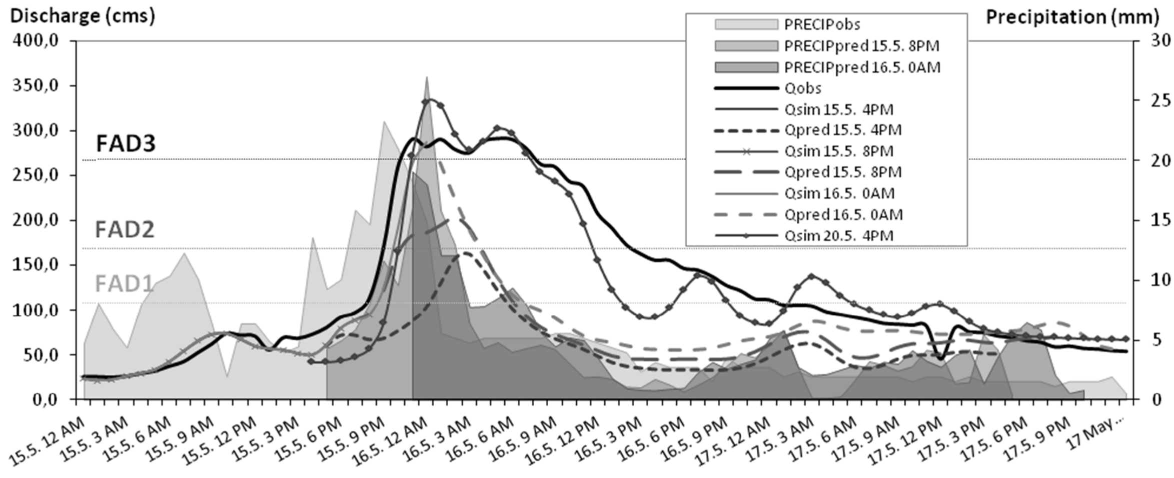

Fig. 3 Gage of Český Těšín – results

For Věřňovice gage models relatively reliably captured the trend of the initial growth of discharge. Compared with the upper intercatchment the peak discharge absolute value was predicted slightly above FAD2 value in all of the evaluated computation runs, but 8 to 10 hours earlier than it was afterward observed (run 15th May 2014 4PM → 352 m^3/s on 16th May 2014 5AM; run 16th May 2014 0AM → 384 m^3/s on 16th May 2014 3AM). Compared to the relatively satisfactory fitness of volume and peak discharge absolute value, the model had problems with the hydrographs timing. The best good-of-fitness of observed and modeled hydrographs was achieved in the computation runs between 17th May 2014

0AM and 19th May 2014 12AM, approximately 4 to 6 days after the beginning of rainfall runoff episode and therefore mostly or completely within simulation part of computation run window. With the increasing shift of the computation run window away from the beginning of the rainfall runoff episode the peak discharge value was gradually overestimated, but there was no significant progress in the good-of-fitness of the hydrographs timing.

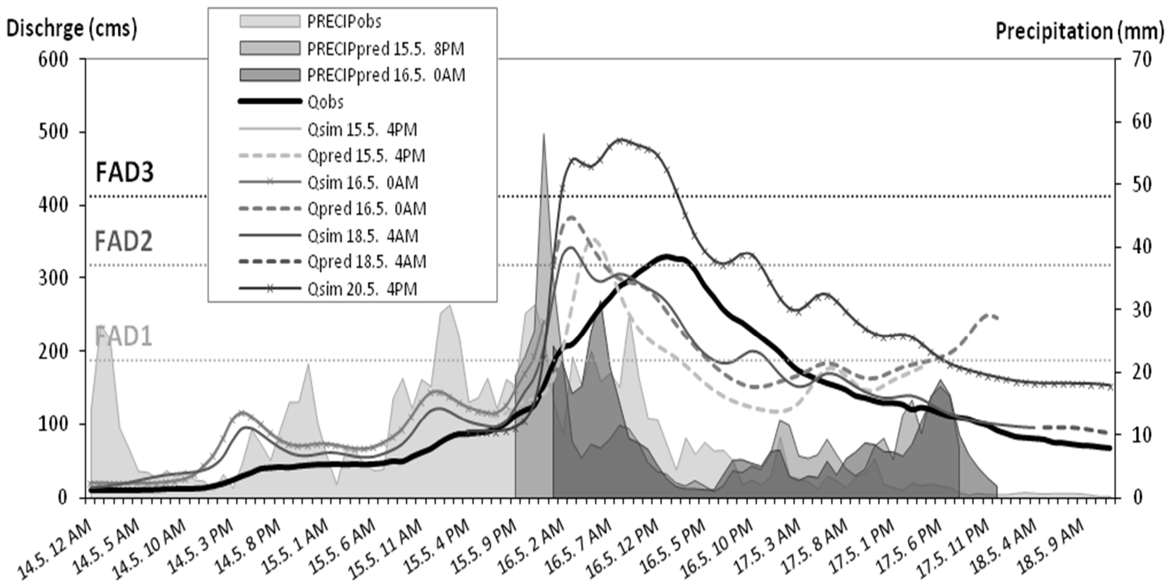

Fig. 4 Gage of Věřňovice – results

TABLE II
PRECIPITATION – GOOD-OF-FITNESS PARAMETERS

Gage	15-52014 4PM			16-52014 0AM		
	ME (mm)	RMSE (mm)	R^2	ME (mm)	RMSE (mm)	R^2
Český Těšín	-0,47	2,20	0,08	-0,44	0,86	0,25
Třinec	0,84	5,03	0,15	0,11	2,14	0,34
Nýdek	0,66	2,72	0,68	-0,03	1,39	0,41
Jablunkov	0,74	2,77	0,40	0,30	0,51	0,47
Suma	1,87	20,75	0,52	-1,00	6,03	0,36

In Table II there is a simple evaluation of the good-of-fitness of observed and predicted hyetographs (for 2 prediction inputs) for the meteorological gages located within the upper intercatchment. There are the values of precipitation mean error (ME), root mean square error (RMSE) and determination coefficient (R^2) values in the table. The gages in the table are arranged in the direction of flow of the river. It is obvious from the table that the actualization of the prediction led to the increase of the good-of-fitness of the observed and predicted hyetographs. The downstream intercatchment is not evaluated from this perspective because the contribution of this part of catchment to the total outflow from whole catchment was minimal.

In Table III there is a simple evaluation of the good-of-fitness of observed and simulated/predicted hydrographs for the gage of Český Těšín. Good-of-fitness is expressed by the values of mean error (ME) and root mean square error (RMSE) of discharges, determination coefficient (R^2), Nash-Sutcliffe efficiency parameter (N-S) [12] and for complete hydrographs also runoff volume error (W) and peak discharge relative error (MF). Evaluation is done for both gages and selected computation runs. Graphical expression of regression relation of observed and simulated/predicted discharge at the gage of Český Těšin is in Fig. 5.

TABLE III
DISCHARGE – GOOD-OF-FITNESS PARAMETERS

Gage	Run	sim / pred	ME (m^3/s)	RMSE (m^3/s)	W (%)	MF (%)	R^2	N-S
Český Těšín	15.5.2014 4PM	sim	-2,12	7,78	-	-	0,6	0,82
Český Těšín	15.5.2014 4PM	pred	97,22	115,04	-	-	0,08	-1,08
Český Těšín	15.5.2014 4PM	sim + pred	26,10	61,66	-59,80	-44,20	0,73	0,54
Český Těšín	16.5.2014 0AM	sim	-0,30	11,34	-	-	0,95	0,95
Český Těšín	16.5.2014 0AM	pred	55,32	84,33	-	-	0,38	-0,1
Český Těšín	16.5.2014 0AM	sim + pred	15,50	45,96	-41,90	1,80	0,76	0,72
Věřňovice	15.5.2014 4PM	sim	-23,06	32,25	-	-	0,67	-1,78
Věřňovice	15.5.2014 4PM	pred	25,72	75,01	-	-	0,23	0
Věřňovice	15.5.2014 4PM	sim + pred	-9,21	48,40	-54,80	-52,20	0,75	0,80
Věřňovice	18.5.2014 0AM	sim	-8,08	36,61	-	-	0,86	0,85
Věřňovice	18.5.2014 0AM	pred	-33,49	36,91	-	-	0	-10,17
Věřňovice	18.5.2014 0AM	sim + pred	-15,29	36,70	19,60	3,90	0,84	0,82

It is obvious from Table III and Fig. 5 that the models gave quite good results in the simulation part of computation run window, but the good-of-fitness was distinctly worse for the prediction. However, the most important characteristics of hydrograph (peak discharge and the rising limb) were predicted reliably for the gage of Český Těšín.

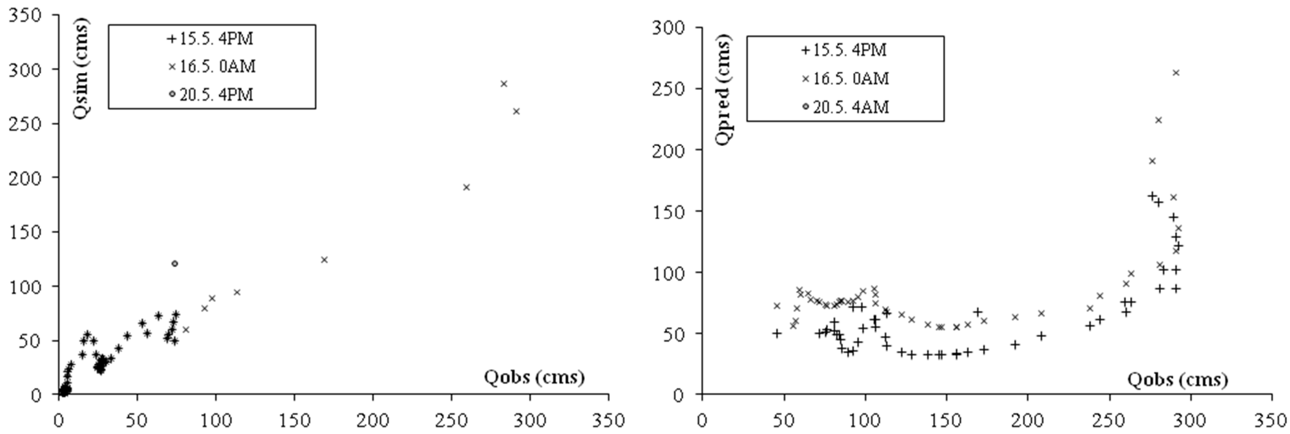

Fig. 5 Gage of Český Těšín – observed (Qobs) vs. simulated (Qsim) flow and observed vs. predicted (Qpred) flow

V. Discussion and Further Development

The May episode of intense rainfall-runoff activity was one of the first sharp tests of system Floreon+ functionality. The results of modeling briefly evaluated above show clear trend in the results of calculations with how the model was gradually filled with updated measurements and predictions of precipitation. Good-of-fitness of observed and modeled hydrographs reached satisfactory values especially for the rising limbs of hydrographs. Apart from the parameterization of the model one of the most important factors influencing the quality of model outputs is primarily the quality of the input dynamic variables – precipitation, both in the measured data and the predictions. Precipitation data entering the model are affected by uncertainties arising from the way of their collection (data observed in the ground meteorological gages network) and uncertainties in predictions of precipitation and its spatial interpretation (conversion of sums of 9x9 km grid to the ground gages). The combination of gradual saturation of the model by the input precipitation and actualization of the precipitation prediction led to the gradual increasing of the prediction of the hydrographs rising limbs and peak discharges. Particularly in the upper catchment models responded to a sharp wave in the predicted hyetographs by rapid decrease of the runoff following after the peak discharge. Less intense but compared to the prediction persistent rain during the 16th May 2014 was then reflected in the significant improvement of the hydrograph falling limb simulation (run 20th 2014 4PM). Worse good-of-fitness in the hydrographs timing at the outlet of the catchment (gage of Věřňovice) was mainly caused by the worse parameterization of the unit hydrograph for these parts of the catchment and also probably due to the manipulation at the dam Těrlicko, which is located within the lower intercatchment.

Experiences with running of the models obtained during evaluated episode are valuable basis for further development of the system. Currently solved issue is schematization of water reservoirs and automatic calibration runs. Currently automatically calibrated model within Floreon+ system is model Math1D, automatic calibration of HEC-HMS model is in the solution. Quite different experience with the response of geologically different catchments to the causal rainfall shows (especially in the catchment of the western part of Floreon+ model domain that are geologically complicated with occurrence of pond systems in the lower part of catchment) that the further refinement of model parameterization and calibration involvement is a prerequisite for further successful operation of the system.

VI. Conclusion

The content of this paper is to evaluate the outputs of one of the rainfall runoff models running within the system Floreon+ and to show successful flood event prediction. Results are illustrated and evaluated for the most eastern catchment of the Floreon+ model domain – the river Olše catchment, and the rainfall runoff episode of middle of May 2014. The results are interpreted by comparison of the observed and simulated/predicted hydrographs for gage Český Těšín and Věřňovice located in the middle and lower parts of the catchment.

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