World Meteorological Organization

STUDY OF HISTORICAL FLOODS IN CENTRAL AND EASTERN EUROPE FROM AN INTEGRATED FLOOD MANAGEMENT VIEWPOINT

CZECH REPUBLIC

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For the WMO/GWP Associated Programme on Flood Management

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1. Introduction

On the 15th July 2002, between 17:30 and 19:00 hours CEST, an extraordinary torrential rainfall occurred in Moravia on the catchment boundary between the rivers Svratka and Svitava in the Counties of Blansko and Žďár nad Sázavou, which caused on the left hand tributaries of the Svratka and on the right hand tributaries of the Svitava a voluminous flood wave. During that time, 171.7 mm of rain was measured in the precipitation measurement station in Olešnice, which is the largest daily sum measured on the territory of South Moravia since the beginning of measurement. This flash flood caused considerable damages and cost two human lives.

2. Description of area

2.1 Natural characteristics

The area affected by the flood is located in the catchment of the Morava River on the catchment boundary between the rivers Svratka and Svitava, North of the District city of Brno. The area is the region of the Upper-Svratka Highland, which is a part of the Bohemian-Moravian Highland, with elevation of around 550 – 650 m A.S.L. The countryside is undulating, with numerous fields, meadows and groups of trees, the hills here join into mountain ridges, which at places steeply fall into the valley, and at places are slowly transferred into a plain.

Among the most severely affected townships/villages were Olešnice, Crhov, Louka, Křtěnov, Kunštát, Hodonín u Kunštátu, Zbraslavec (County Blansko) and Štěpánov (County Žďár nad Sázavou). Through the municipalities of Olešnice, Křtěnov and Hodonín, the Hodonínka rivulet flows (stream of 5th order, Svratka catchment), which springs at an elevation of 652 m A.S.L. near the village of Nyklovice. In Olešnice, in the middle of the township, the Veselský Creek, which is piped within the township, joins the Hodonínka. The Hodonínka joins Svratka in Štěpánov at an elevation of 340 m A.S.L., where it flows from the east. The average slope of the Hodonínka catchment is 13.2 %. Through the village of Crhov, the Crhovský Creek flows, which joins the Hodonínka under Křtěnov. The municipalities of Kunštát and Zbraslavec lie in the catchment of the Svitava River.

The geological underbed strata originated in the Cambrian era, and is created especially by crystallic slates, paragneisses, mica schists and phylites. In decrements, the solid rocks are overlain by unconsolidated sediments (especially by clays and sands).

The soil cover is created by Cambisols (brown soils) and podzols. The forest cover is approximately ... %.

2.2 Climatic characteristics

The average yearly precipitation sum in the catchment of the Hodonínka rivulet is 669 mm, in the catchment of the Úmoří Creek this value is also 669 mm (for the period of 1931 – 1980). The average yearly distribution of temperatures in the station of Bystřice nad Pernštejnem and average monthly precipitation sums in the station Olešnice are quoted in the Tables no.1 and 2.

Tab 1. Average yearly distribution of temperatures – station Bystřice nad Pernštejnem

Month	1.	2.	3.	4.	5.	6.	7.	8.	9.	10	11.	12.	Year
Air Temperature [°C]	-3,1	-1,8	2,1	6,5	12,1	14,7	16,5	16,2	11,9	7,0	1,4	-1,7	6,8

Tab 2. Average monthly precipitation sums – station Olešnice (for period of 1971-2000)

Month	1.	2.	3.	4.	5.	6.	7.	8.	9.	10	11.	12.	Year
Precipitation [mm]	40	34	40	42	65	77	79	65	54	40	46	45	629

2.3 Hydrological characteristics

Basic data of the catchments of the Hodonínka Rivulet and the Zbraslavec Creek are shown in the Table no.3 and 4:

A - Catchment area
L - Length of thalweg
$\mathbf{H_{avr}}$ - Average elevation of catchment
i - Average slope of thalweg
α - Catchment characteristics
Forest cover

Tab 3. Basic data of the Svratka catchment

Cross-section number	Stream	A [km^2]	L [km]	H_{avr} [m a.s.l.]	i [%]	α [A/L^2]	Forest cover [%]
1	Hodonínka above the village of Olešnice	15.87	8.2	635	1.56	0.24	16
2	Hodonínka above the Veselský Creek	17.65	10.1	628	1.53	0.17	15
3	Veselský Creek	5.13	3.5	595	3.52	0.42	5
4	Crhovský Creek, village of Crhov	7.96	4.5	597	2.20	0.38	10
5	Hodonínka above the Dvorský Creek	36.15	13.3	619	1.26	0.20	13
6	Dvorský Creek	3.25	2.9	586	6.26	0.39	5
7	Hodonínka under the confluence with the Rozsečský Creek	47.27	17.0	589	1.17	0.16	20
8	Hodonínka Rivulet, village of Štěpánov	66.78	21.3	587	1.41	0.15	30

Tab 4. Basic data of the Svitava catchment

Cross-section number	Stream	A [km^2]	L [km]	H_{avr} [m a.s.l.]	i [%]	α [A/L^2]	Forest cover [%]
9	Úmoří Creek, Zbraslavec Creek	32,10	7,7	543	4.12	0.54	40

2.4 Social characteristics

In the region there are the townships of Olešnice and Kunštát, and a number of villages of a rural type. Agriculturaly, this area can be denoted as a potato- and corn-growing region, animal production is aimed predominantly at the breeding of cattle, industry is concentrated especially in Olešnice.

In Olešnice, four retarding basins for flood mitigation purposes have been built.

Number of inhabitants:

Township/village	Number of inhabitants
Olešnice	1774
Crhov	187
Louka	78
Křtěnov	212
Kunštát	2621
Zbraslavec	181
Štěpánov	720

3. Meteorological causes of the flood

3.1 Development of weather situation in the first half of July 2002

In the first decade of July 2002, or roughly till 11th July, weather in our country was determined by a region of low air pressure, which was being kept or renewed in the region of the North and Norwegian Sea, and Great Britain. Around this region of low pressure, relatively warm air from the South-West was flowing to our country, and warm weather was only transiently interrupted by precipitation, mainly together with storms, which however above Moravia did not reach excessive intensity. A significant rearrangement of the weather situation occurred on the 10th and 11th July, when after the passing of a cold front, which in essence did not manifest itself over Moravia precipitation-wise, a pressure high started to spread from Western to Central Europe and over Scandinavia, which, after short slight cooling, brought to our territory sunny weather without precipitation.

The pressure high however relatively quickly receeded to the North over Scandinavia, and around a pressure low, which was created over North Italy, very warm and moist air started to flow to our territory from the Balkans on Saturday 13th and Sunday 14th July. This warm and moist air was further being warmed, whereby suitable conditions for the origin of storms were being created. Storms indeed did occur on a larger scale over Central Europe and over Moravia already on Saturday 13th July. On the following day the storm activity over the Czech Republic partly weakened, but on Monday 15th July it again increased.

As a result of the quoted development of the weather situation, above-normal weather prevailed in Moravia in the first half of July, with average daily temperatures from 17.7°C in Nedvězí to 21.9°C in Brno, which is approximately 2.5 - 3°C above the long-term average. Up till 12th July, more abundant rainfalls mostly did not occur, perhaps with the exception of 2nd, 4th and 7th July, when showers and storms did occur, which were however of weak to mild intensity. Precipitation totals on monitored stations of Southern and Central Moravia in the first half of July reached around 70-130 % of the long-term average.

3.2 Weather situation and development of convective storms on 15th July 2002 over Moravia

The weather analysis is illustrated by a picture of objective analysis of meteorological fields in various levels on Fig. 1 (in Appendix). Almost in all levels from the earth to the tropopause the pressure low can be seen, which had its centre in the region of Corsica, and around which warm air was flowing to our territory from the East or South-East. Near the ground, weak or mild wind from the North-East was mostly blowing, but this did not bring any cooling, because warm air was also above the South-Eastern half of Poland.

The morning in Moravia was half-overcast, The Bohemian-Moravian Highland had a solitary low cloudiness or fogs. Numerical weather forecast models (the Aladin model and the model of the German weather service) forecast on the given area in the period of 14:00 to 20:00 hours CEST only up to 5 mm of rainfall, while it is known, that especially storm precipitation is hard to predict by these models, as opposed to large-area rainfalls. According to a Brno radio-probe station, the atmosphere was unstable (moisture-unstable), i.e. conditions existed for the origin of a storm, however no index of instability had an extraordinary value.

According to information from meteorological radars (see Fig. 2, Appendix), a zone of showers and storms was advancing in the morning hours from Austria towards the North and was partially weakening. Around noon, rather local storms occurred in the region of the Jihlava hills, and these were advancing further to the North-West. For further development, further storms were important, which were created in the Žďár nad Sázavou region, about 20 to 30 km from the afflicted area, around 16:00 hours. Out of these, cool and moist air was "flowing out", whose face on the South-Easterly side was stimulating the creation of further storm cells, which were hence drawing near the afflicted region ***against*** the direction of the prevailing Southerly flow in the troposphere.

Around 17:00 hours CEST, a significant storm cell was created several kilometres East of Olešnice, and soon substantial rainfalls began in the region around Olešnice. The outflows from these storms initiated the creation of further strong output movements, which however did not advance further to the South-East, but repeated themselves on almost the same region, where therefore occurred an extraordinary accumulation of torrential rainfalls. Only around 19:30 CEST their impact shifted by about 5 to 10 km further to the South-East, and around 20:00 hours the development of storm cells overall began to weaken.

It must be said, that apart from staying in one spot, the appearance of these storms was not too conspicuous and not even further information, which were at the meteorologists' disposal, pointed to a disaster of such extent.

The parameters of the atmosphere indicated, that strong convective storms with dangerous weather phenomena will occur, and therefore already on the 13th July an appropriate warning was given out for the days of 13th to 17th July 2002. During a regular consultation of the Central and Regional Forecasting Workplace in Brno in the morning of the 15th July 2002, it was decided to leave the quoted warning in place.

4. Hydrological situation

Before the flood event, water levels of streams in this area were low, flows from 10th July 2002 on the upper Svratka River in the watergauging station Borovnice were on the level of 250- to 335-daily discharges. In the watergauging station Bílovice on the Svitava River, the flows from 10th July 2002 were at the level of 240- to 330-daily discharges. Water levels up to the 13th July were stable, on the 14th July a slight increase of the water levels occurred.

There is no watergauging station directly in the afflicted area. On the upper Svratka above this area are watergauging stations in Borovnice and in Dalečín, another watergauging station is under the Vír Reservoir. The closest station south of the afflicted area is Veverská Bítýška on the Svratka River. In the catchment of the Svitava River there is a watergauging station in Letovice on the Svitava and in Prostřední Poříčí on the Křetínka River. In Olešnice there is a precipitation-measuring station of the CHMI Brno Regional Office.

On the 15th July 2002 after torrential rainfalls between 17:30 and 19:00 hours a flood wave was created, which receeded approximately at midnight. Most affected were left hand tributaries of the Hodonínka Rivulet: Veselský Creek and Crhovský Creek. Approximately at 19:30 hours, the Mayor of Hodonín u Kunštátu broadcast on the local radio, that a torrential floodwave is approaching Hodonín from Olešnice. In the course of twenty minutes, water level reached 2.5 m in a place where the normal stage is 10 cm. This situation lasted for about 4 hours. According to local inhabitants, the Hodonínka Rivulet was 40 to 50 m wide in a place where the normal width is 2 m.

In the region, the following streams were affected by the flood wave: Hodonínka, Veselský Creek, Crhovský Creek, Dvorský Creek, Loucký Creek (Svratka catchment), Petrůvka Creek, Sebránek Creek, Sychotínský Creek, Úmoří Rivulet (Svitava catchment).

In the morning after the flood on the 16th July 2002, two cars of the CHMI Brno Regional Office were sent into the afflicted area with 6 workers of the Hydrology Department to map the afflicted area, survey stream cross-sections and high water marks, perform stream gauging, acquire photo-documentation and gain data on the amount of fallen precipitation – see Tab. 5. Out of this field work, peak discharges were evaluated in 10 cross-sections (see Fig. 4). Two cross-sections in Štěpánov on the Hodonínka Rivulet were surveyed and evaluated on the 22nd July 2002. The results of the measurements appear in Tab. 3.

The precipitation-measurement station in Olešnice on the 15th July 2002 recorded a daily precipitation sum of 171.7 mm (see Tab. 6). This was a torrential rainfall with a return period of $n > 200$ years. Precipitation is being measured in Olešnice since 1923. The average yearly sum of precipitation for the period of 1931-2001 is 652 mm, and the average precipitation sum for July for the same period is 80 mm. The maximum daily precipitation sum was recorded in July 1997 – 89.6 mm. In 1997 however it was not a torrential rainfall, but a long-lasting moderate rain.

Tab 5. Causal precipitation sums on the 15th July 2002 – data according to measurement by local inhabitants

Locality	Precipitation sum in mm
Sychotín (Kunštát) upper part of village near petrol station	160
Rozseč – upper part of village under the byre house no. 43	103 120
Crhov – upper part of village (4 measurements)	141 - 192
Lamberk (lonely house above Olešnice)	131
Louka - house no. 4	150

Table 6 quotes daily precipitation sums recorded in the Blansko region and in the vicinity on the 15th and 16th July 2002 in the CHMI stations. The isohyets are shown on Figs. 4 and 5 of the Appendix A.

Tab 6. Daily precipitation sums – monitoring by CHMI Brno Regional Office

Station	Precipitation	Hail	Precipitation	Hail
	15.7.2002		16.7.2002	
Jevíčko (ČHMÚ P-Ostrava)	0,5	No	12,1	No
Vír	27	No	47,4	No
Nedvězí	52,4	No	29,4	Yes
Březová nad Svitavou	3,4	No	34,7	No
Polička	5,2	No	18,9	No
Hradec nad Svitavou	1,4	No	25,5	No
Letovice	9,7	No	40,4	No
Lhota Rapotina		No	28,8	No
Knínice u Boskovic		No	34,8	No
Protivanov	0,1	No	16,7	No
Sloup		No	22,2	No
Rozstání	Not monitored			
Blansko	0	No	29	No
Synalov	16,7	No	38,2	No
Sejřek	40,8	No	59,8	No
Štěpánov nad Svratkou	15,8	No	46,5	No
Úsuší - Čížky	0,5	No	39,2	No
Kuřim		No	32,2	No
Velká Bíteš	Not measurable	No	66	No
Skřinářov	0,2	No	56,4	No
Bystřice nad Pernštejnem	4,1	No	41,9	No
Věcov - Jimramovské Pavlovice	5,8	No	31,9	No
Olešnice	171,7	No	14,7	No
Lísek	Not measurable	No	35	No
Nové Město na Moravě	10,1	No	45,9	No

Tab 7. Peak discharges on the 15th July 2002

Svratka catchment

Cross-section number	Stream	A [km^2]	Q_{max} [m^3.s^{-1}]	Max. specific runoff q_{max} [m^3.s^{-1}.km^{-2}]	Q_{100} [m^3.s^{-1}]	Return period
1	Hodonínka above the village of Olešnice	15,87	8,5	0,536	30	2-5
2	Hodonínka above the Veselský Creek	17,65	16	0,907	30,5	10-20
3	Veselský Creek	5,13	27	5,263	15	> 200
4	Crhovský Creek, village of Crhov	7,96	42	5,276	20	> 200
5	Hodonínka above the Dvorský Creek	36,15	76	2,102	43	> 200
6	Dvorský Creek	3,25	20	6,154	13	> 200
7	Hodonínka under the confluence with the Rozsečský Creek	47,27	110	2,327	50	> 200
8	Hodonínka Rivulet, village of Štěpánov	66,78	110	1,647	60	> 200

Svitava catchment

Cross-section number	Stream	A [km^2]	Q_{max} [m^3.s^{-1}]	Max. specific runoff q_{max} [m^3.s^{-1}.km^{-2}]	Q_{100} [m^3.s^{-1}]	Return period
9	Úmoří Creek, Zbraslavec Creek	32,10	22	0,685	25,5	50

A response to the extraordinary precipitation activity from 15th July 2002 on the Svratka River in Veverská Bítýška came on the 16th July 2002. The discharge here peaked at 5:30 hours, reached 60 m^{3}s^{-1} (approximately Q_1) and the I. DFA (Degree of Flood Activity) was exceeded. The duration of the I. DFA was 16th July 2002 from 2:50 to 9:30 hours. The volume of the flood wave was 1.6 – 1.8 million m^3 of water.

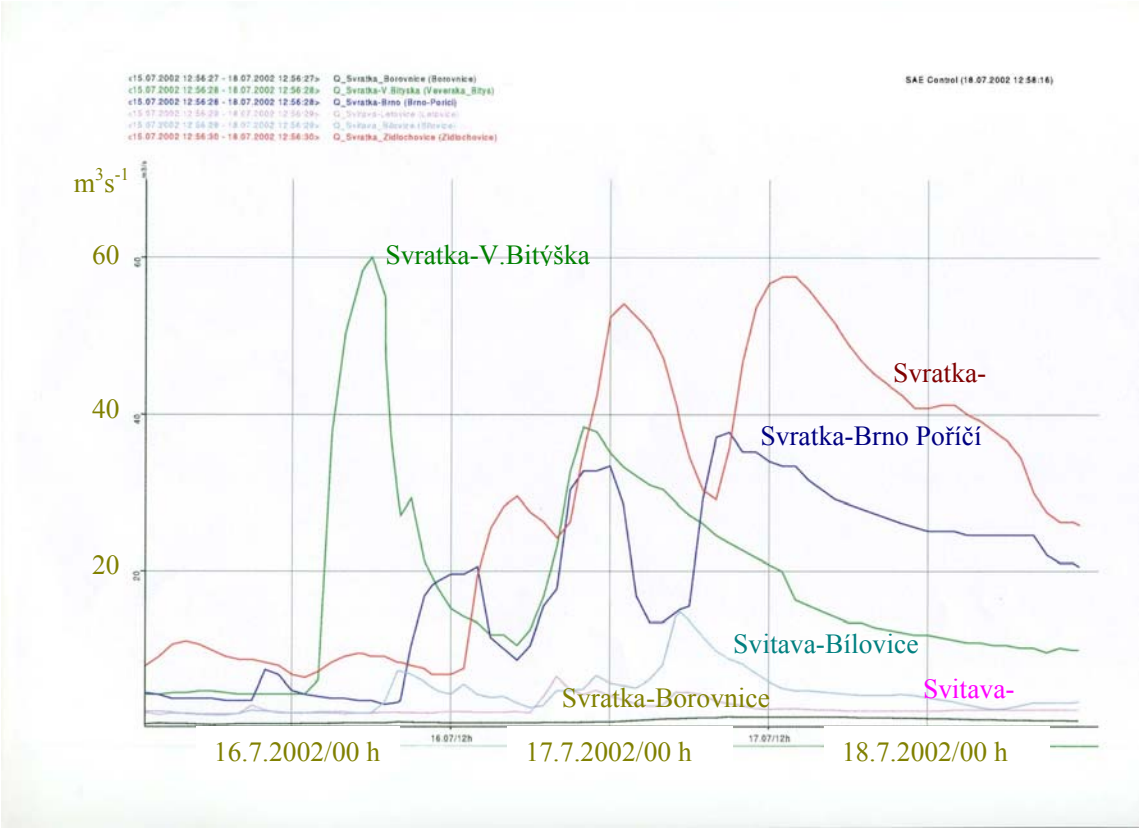
In the watergauging station Prostřední Poříčí on the Křetínka River (Svitava catchment), the discharge before the flood was about 0.1 m^{3}s^{-1}. On the 15th July 2002, the discharge peaked at 21 hours with 4.54 m^{3}s^{-1} – smaller than 1 year discharge. In the watergauging station Letovice on the Svitava River on the 15th July 2002 at 21:00 hours, a maximum discharge of 1.99 m^{3}s^{-1} was recorded, which was an increase of about 1 m^{3}s^{-1} compared to the previous discharges.

As can be seen from the hydrographs, a greater response to the torrential rainfall was manifested in the Svratka catchment, while the Svitava catchment was affected substantially less. In the Svratka catchment, the left hand tributaries registered maximum discharges with a return period greater than 200 years, while in the Svitava catchment the most affected were right-hand tributaries Petrůvka Creek and Úmoří Rivulet,

which registered maximum discharges with a return period of 50 years. The Úmoří Rivulet is a right-hand tributary of the Svitava River down below the Letovice watergauging station.

Hydrograph

Average hourly discharges
Svratka and Svitava 16.7. – 18.7.2002



Verification of discharge by hydraulic calculation according to Chezy's Equation

- Stream: Hodonínka
- Cross-section: Village Štěpánov nad Svratkou (Fig. 2 – cross-section 8)

- Input data:

Cross-sectional area	$A = 27.6\ m^2$
Wetted perimeter	$P = 16.12\ m$
Hydraulic radius	$R = 1.712$
Water surface slope	$i = 0.007$
Roughness coefficient	$n = 0.030$

Chezy's Equation for average cross-sectional velocity $v_a = C\,(Ri)^{0.5}$,

Discharge $Q = AC\,(Ri)^{0.5}$

Velocity coefficient C is determined according to Agroskin $C = 17.72\,(K + \log R)$, where

K = 1.88 (according to tabulated values of K quoted for various types of river bed on p. 106 of Hydrological Handbook by A. Cherkashin).

Average cross-sectional velocity

$$v_a = 37.39 \times 0.109 = 4.07 \text{ ms}^{-1}$$

Discharge

$$Q = 4.07 \times 27.6 = 112.33 \text{ m}^3\text{s}^{-1}$$

The average cross-sectional velocity according to the Chezy's Equation in the river cross-section reached 4 ms^{-1} for a water surface slope of 0.7 %. The discharge determined by the above-quoted way corresponds to the results of field watergauging and especially to the fact that the drag force of the water stream was so large that it removed even large boulders in the river bed.

5. Warning system

As already has been mentioned, meteorologists gave out already on the 13th July an appropriate notice of torrential precipitation. A caution was not given out, because nothing pointed to a disaster of such extent.

In higher-lying municipalities, inhabitants were not cautioned in any way. In the village of Hodonín, the Mayor at 7:30 p.m. announced on the local broadcasting system, that a flood wave is approaching the village from the township of Olešnice. This warning contributed at least to a partial rescue of the property of the local inhabitants, and maybe also to the rescue of human lives.

6. Rescue works

Fire Brigade units came to the flood-struck area still in the same evening. It was however difficult to get directly to the affected area and the situation during the night became very chaotic. That's why the units were able to act only on the following day in the early morning hours. The civil defence unit from the village of Bučovice also joined in the action, as did volunteers from the surrounding municipalities. In the village of Zbraslavec on the 16th July, inhabitants of six houses were evacuated. Excavators were used to remove the damages. Work was needed especially to free stream beds, to remove mud from flooded houses and to pump water from cellars. Efforts were being made to restore energy supply, and drinking water was being carted to the affected communities.

On the 17th July, the Flood Commission meeting for the integrated Dyje catchment was convened. By the decision of the Leader of the South Moravian District, danger state for the period of 20 days was called in five municipalities from the 17th July.

During the rescue works, information problems between the individual rescue teams occurred, however these were not of a serious character. It may be said, that everyone gave a maximum and unselfish effort.

Representatives of the Government of the Czech Republic visited the affected communities, as did psychologists, who were helping the local population to overcome the psychical shock.

7. Flood damages

The flood wave in the afflicted villages destroyed roads, flooded cellars, and endangered the stability of several tens of houses. Two women lost their lives.

The most afflicted village was the village of Crhov. Out of the total number of 60 houses in the village, 30 were damaged in some way. An asphalt road, not quite two months old, was completely destroyed.

In Olešnice, 5 houses were under water, 135 houses were damaged, also damaged were the bathing pool, library, Cultural Centre and a sewage treatment works. In Olešnice during the last 5 years, flood mitigation measures built consisted of dry retarding basins on the Veselský Creek to protect the village from 40- to 50-year flood. The retarding basins however could not hold the force of the water, and their dam wall was breached. Damage to the dam wall was estimated to be 5 to 6 million Czk.

Flood-caused damages to property, which comes under the Administration and Upkeap of Roads in Blansko, was preliminarily estimated by road experts to be 25 to 30 million Czk. The most serious damage was a completely destroyed bridge on a road of third class between the villages of Olešnice and Hodonín. Only about a metre footbridge was all that remained from the road bridge. Among other damaged road sections was the road between the villages of Rozseč and Kunštát, on the main road connecting Žďár nad Sázavou, Boskovice and Prostějov. About 10 km of roads were damaged. More damaged were local roads, in some villages the footpaths and local road were completely obliterated. The Žďár region had large road damages.

Tab 8. Estimation of damages caused by flood in millions of Czk

Village	Municipal property	Private property
Olešnice	8 – 10	15 až 20
Crhov	15	25
Křtěnov	4	0,5
Zbraslavec	1,5	0,5 - 1
Hodonín	2,5	5
Kunštát	1	1,5
Louka	0,5	0,3
Svitávka	1,5	0,5
Estimates of some other damages		
Lesy ČR	10	
Olešnice – Dairy	5 až 7	
Administration and Upkeap of Roads	67	

Source: Information from Mayors and company directors published in the daily "Southern Moravia Today" (Jižní Morava Dnes) on the 18th July 2002.

8. Conclusion

A flash flood occurred in the affected region, which was caused by an extraordinary torrential rainfall, which was an extreme daily rainfall sum with a Return Period greater than 200 years.

The occurrence of these torrential rainfalls may not be in the forecast precisely localised. According to the information from meteorological radars it may be determined with a considerable error of estimation and with a certain time delay, caused by the procedure of data processing. The time delay of data obtained by the method of remote detection, and the great dynamics of strong storms are the main limiting factors during the giving out of the appropriate warnings.

With the development of meteorological and hydrological modelling there however exists a hope, that in future we will be able to flexibly react to sudden atmospheric changes, and that we will in this way prevent not only material damages, but especially losses of human lives.

References

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- Fig. 2 Situation – surveyed cross-sections in the Svratka catchment
- Fig. 3 Information from meteorological radars
- Fig. 4 Daily precipitation sums from the 15.7.2002
- Fig. 5 Daily precipitation sums from the 16.7.2002

Appendix B

- Photodocumentation

Appendix A

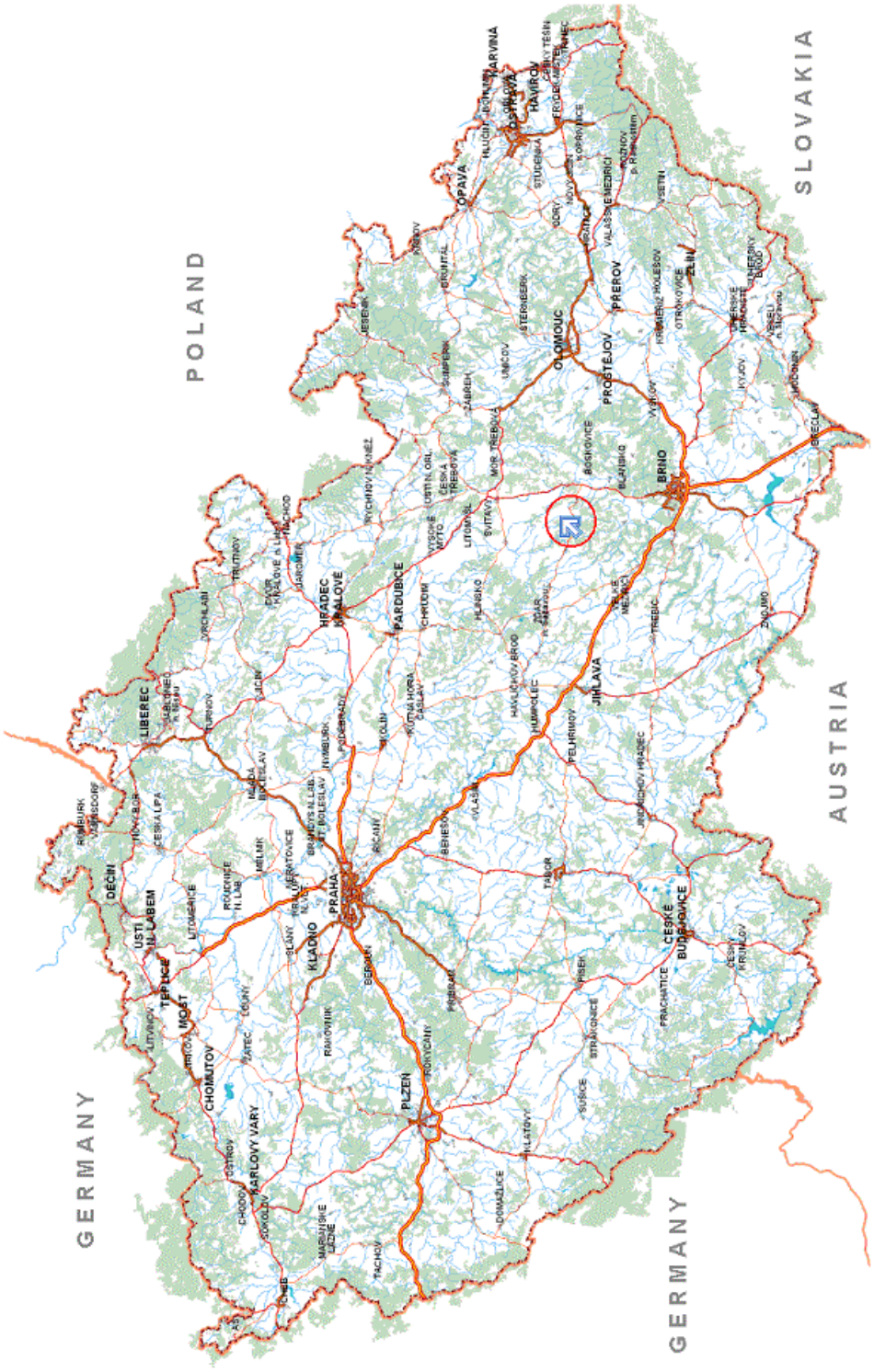

Fig 1. Situation – area affected by the flood on the 15.7.2002

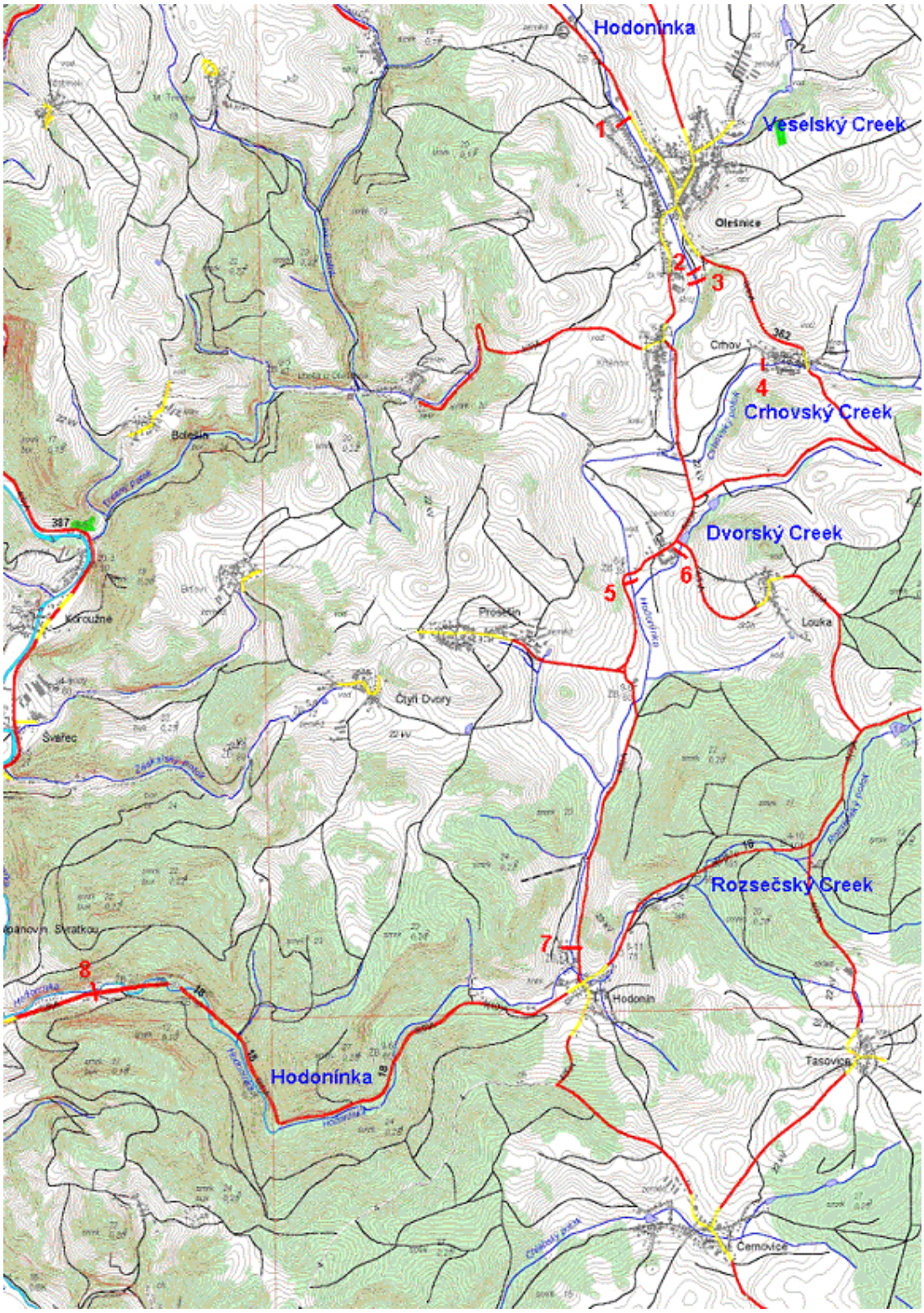

Fig 2. Situation – surveyed cross-sections in the Svratka catchment

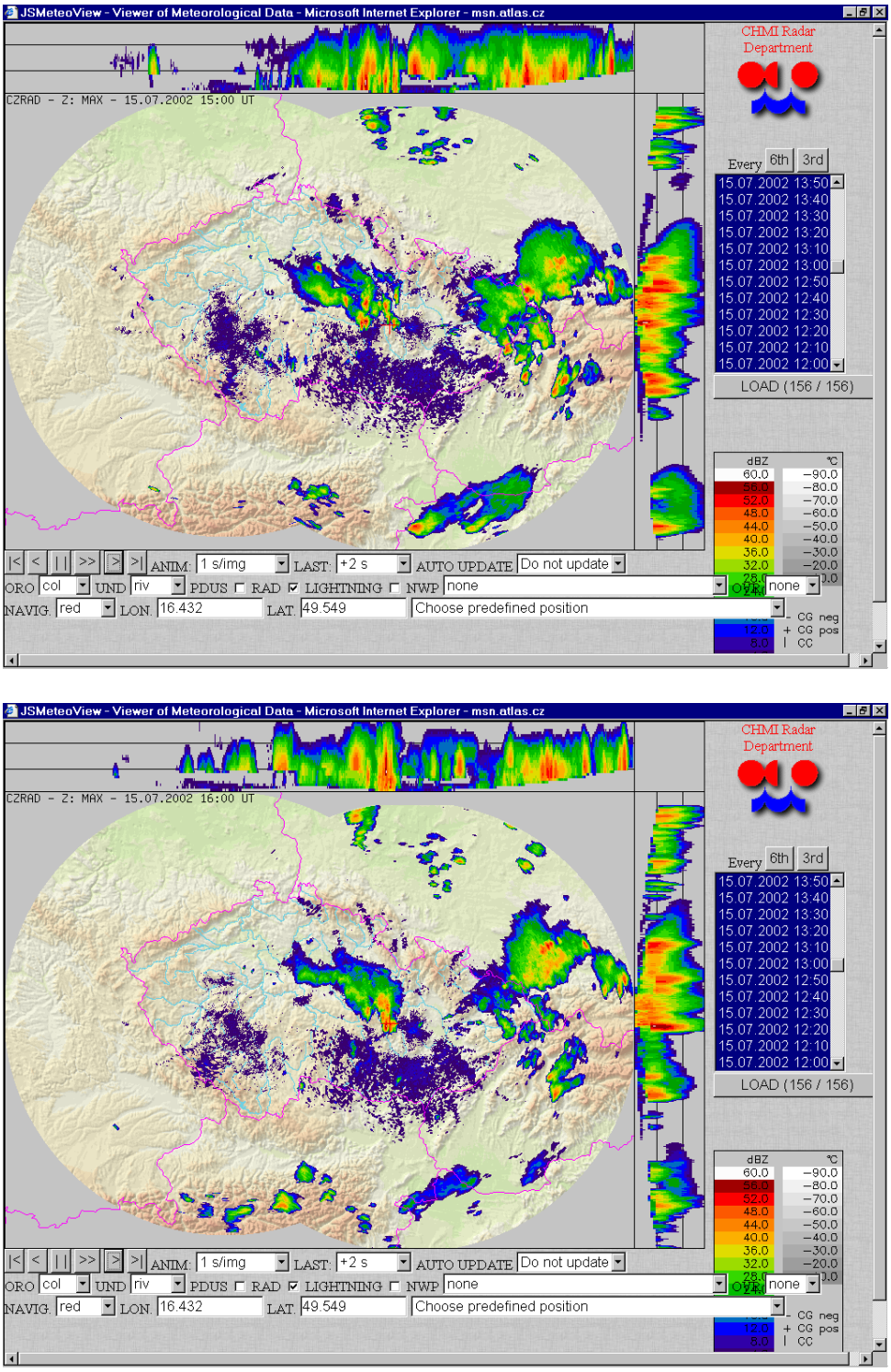

Fig 3(a). Information from meteorological radars from 17, 18, 19 a 20 hours CEST on the 16.7.2002 (15, 16, 17 and 18 hours UTC – world time). Township of Olešnice is denoted by a little red cross.

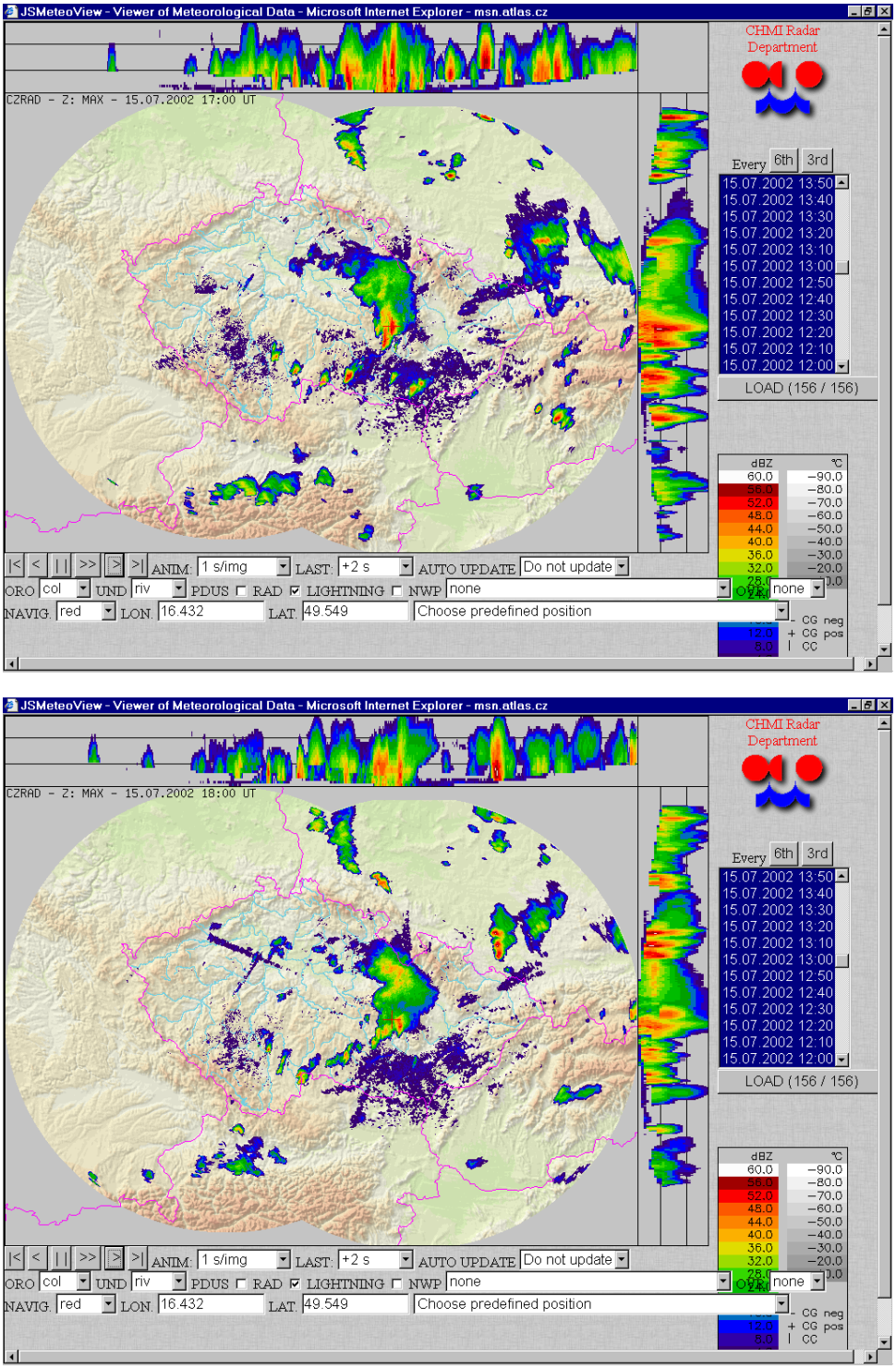

Fig 3(b). Information from meteorological radars from 17, 18, 19 a 20 hours CEST on the 16.7.2002 (15, 16, 17 and 18 hours UTC – world time). Township of Olešnice is denoted by a little red cross.

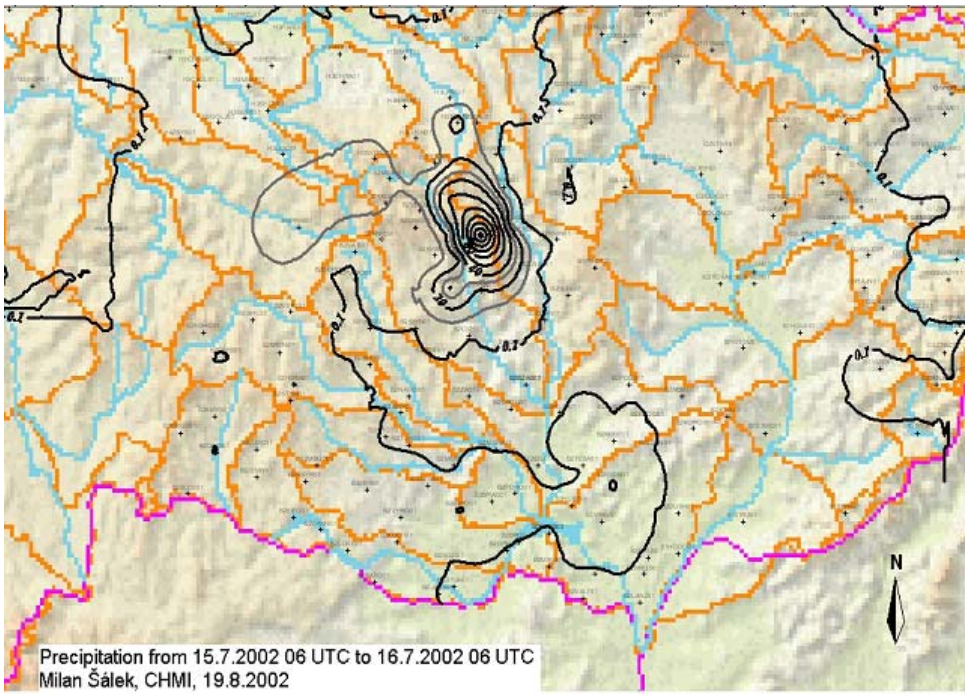

Fig 4. Daily precipitation sums from the 15.7.2002

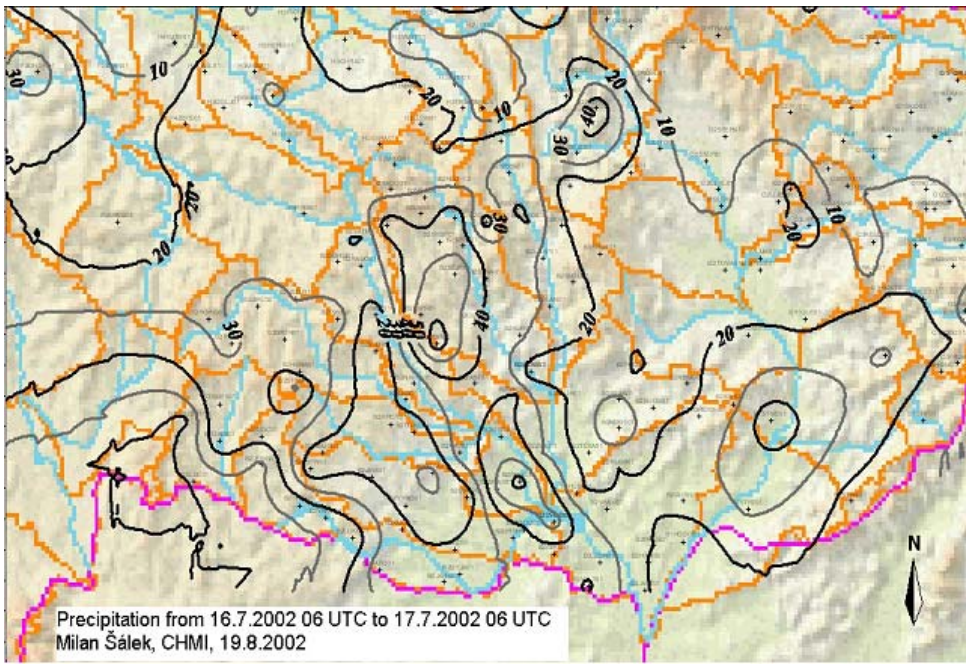

Fig 5. Daily precipitation sums from the 15.7.2002

Appendix B – Photo documentation

Township of Olešnice – Veselský Creek in piping on the 16.7.2002

Deposits of gravel, clay and small stones in the l7ow part of the township under the dairy. The high water mark can be seen on the houses on the right. The road has already been scraped. The maximum discharge here has been evaluated to be 27 m^3/s.

The affected part of the township, street below the dairy, a scour hole about 2 m deep. The Veselský Creek is piped under the road.

Road between Hodonín u Kunštátu and Štěpánov – Hodonínka Rivulet on the 22.7.2002

Damaged road and bridges between Hodonín u Kunštátu and Štěpánov in a section approximately 7 km long, where the average water velocity (v_{ave}) reached 4 m/s.