Runoff Processes and Land Use Changes in the Upper Reaches of the Krupá River Catchment during the Last 70 Years

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Abstract: In this paper, the authors summarise the land use changes in the upper reaches of the Krupá River catchment, which is a left tributary of the Morava River. During last 70 years, the catchment was exposed to many important historical events that have been inscribed in the physique of the landscape in a very interesting way. The land use changes, which occurred during the last eight decades in the subcatchment of the Krupá River basin, have been analysed using historical maps, cadastral maps, and both historical and recent aerial photographs of the area. The next step is to estimate, through the CN method and DesQ hydrological model, how the runoff processes in the Krupá River catchment could be influenced by the land use changes.

Keywords: land use changes; surface runoff; CN method; DesQ hydrological model; small catchment

Extensive land exploitation by over – intensified agriculture in the past has decreased natural retention and accumulation capacities of the catchment areas in the Czech Republic. Many natural barriers to the surface runoff have been removed; inappropriate land use, namely incorrect agricultural and forestry practices such as monoculture cropping in both fields and forests, along with the effects of heavy machine induced soil compaction, have significantly decreased infiltration capacities (Kovář *et al.* 2002).

During the evaluation of the serious flood events which occurred in the Czech Republic in recent years, one of the proposed and much disputed reasons for the severity of the floods is the decreased retention and accumulation function of the landscape. The destructive effects of "flash floods" tend to impact agricultural catchments, especially those with insufficient land cover that had intensive runoff generation and where insufficient soil infiltration capacities prevail. On the other hand, the changes have been implemented to the landscape since the first half of the 19th century, which have been generally connected with the development of the society; these facts have been summarised by Bičík and Jeleček (2003).

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Models simulating the retention capacity of catchments are used for planning the landscape structural changes at the regional scale, for example, WBCM (Kovář *et al.* 2002), DesQ model (Hrádek & Zezulák 1998), WMS and AGNPS, which have been tested particularly for the very specific conditions prevailing in the Czech Republic. Problems arising from the use of these models are primarily connected with the lack of direct hydrometric observations in a majority of small watersheds, which might otherwise be the basis for model calibration.

Hydrologic effects of the land use changes have been thoroughly described by Calder (2005). The major changes affecting the hydrological status of a catchment are in particular: forestation and deforestation, intensification of agriculture, drainage of wetlands, road construction, and urbanisation. The land use changes in the Czech Republic have been affected by important historical events during the last 70 years.

The main aim is to estimate, through the CN method and DesQ hydrological model, how the runoff processes in the upper reaches of the Krupá River catchment could be influenced by the land use changes. No gauging station is located in the upper reaches of the Krupá River catchment. Therefore, a hydrological model DesQ was used. This model was calibrated by means of verifying the modelled outputs with actual measurements from the CHMI stations for the selected catchment areas in the Czech Republic. The outputs of hydrological modelling as obtained without measured gauging data cannot fully guarantee the accuracy in comparison with the modelling of the actual runoff processes measured in the catchment area.

MATERIAL AND METHODS

The Krupá River catchment (left tributary of the Morava River) serves as the general study area. The Krupá River has a total drainage area of 112 km^2 and its length is 23 km. The long-term average annual precipitation in the catchment is about 1010 mm and the long-term runoff is about 560 mm. In this paper, the authors selected the upper reaches of the Krupá River catchment. Its drainage area is 1520 ha (Figure 1).

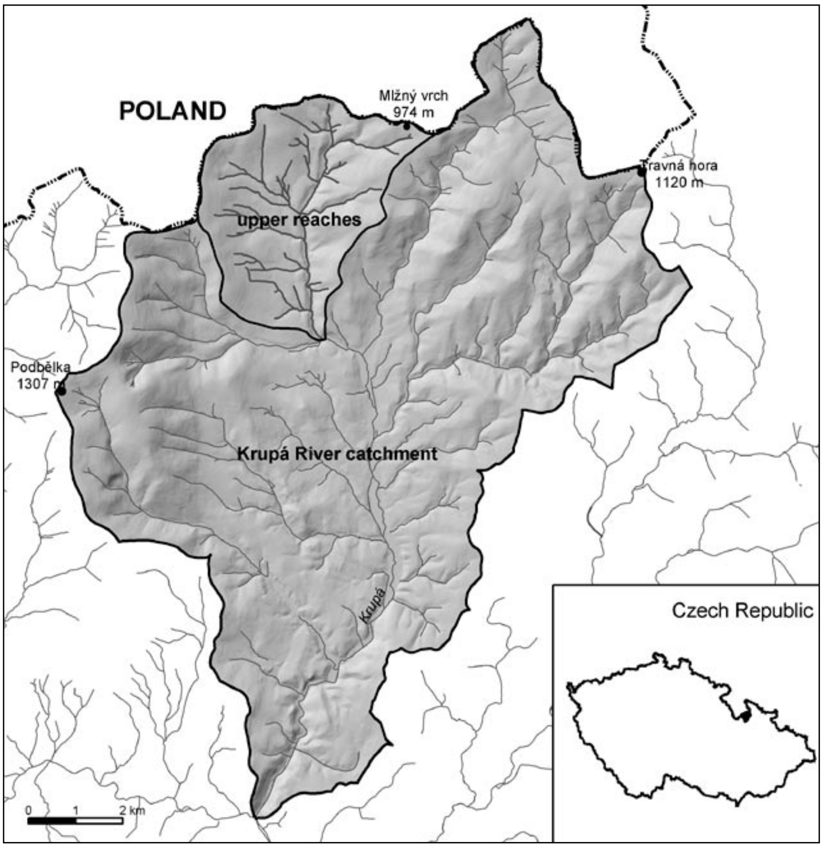

Figure 1. Location of the Krupá River catchment

During the last 70 years, the Krupá catchment was exposed to many important historical events that have been inscribed in the physique of the landscape in a very interesting way. The first important historical event in the 20th century in the area was the displacement of German inhabitants after the Second World War. On aerial pictures from 1936 we can see the preferred land use, namely an agricultural system based on a high number of small fields, many hedgerows and balks.

Under the communist regime, the land was cultivated by family-farm owners until 1948. This type of farming was transformed into a large-scale intensive agricultural production. This radical change had a significant impact on the structure of the landscape. Small plots, balks and hedgerows were destroyed. Small parcels were collectivised. The state-owned Staré Město Cooperative, located in the Krupá River catchment, was established in 1965.

The transformation of agriculture since 1989 has also impacted the land use. In the Krupá River catchment, a large amount of arable land has been changed into permanent grass growths as a result of the state deficiency payment (Table 1).

Table 1. Structure of agricultural land in the Krupá River catchment (Chmelová *et al.* 2006a)

	1845 (%)	1948 (%)	1990 (%)	2000 (%)
Arable land	81.6	86.2	34.9	15
Grassland	18.4	13.8	65.1	85

The DesQ hydrological model and the CN method are used to simulate the effects of these land use changes on the runoff processes. The runoff from the area of the subcatchments under study was calculated using the US Soil Conservation Service (SCS) method (US SCS 1975). The CN curves are usually estimated from handbook tables which list the land-use, hydrological soil group, and the antecedent moisture conditions. The SCS method was modified because of specific conditions prevailing in the Czech Republic. The official methodology (handbook tables) was published by the Research Institute for Soil and Water Conservation, Prague (in Czech VÚMOP) in 1992. The hydrologic soil group of the agricultural land in the research area for the years 1930 and 2002 was defined on the basis of the main soil unit in accordance with the methodology of Janeček *et al.* (1992). The equivalent of the hydrologic soil group for forest soils was again determined for both years (1930, 2002) using the method of Macků (2000). The CN curves determination for forest hydrological soil group in the subcatchment was figured out according to the forest age structure and its species composition (Chmelová 2006; Chmelová *et al.* 2006b).

The DesQ hydrological model is used to calculate the maximum water flow in ungauged small watersheds (Hrádek & Zezulák 1998). By "small watersheds" we understand those of area less than 5 km^2 and with an insufficient number of hydrologic stations. It is possible to visualise the catchment in this model as "an open book" where the spine is a depression line and "the covers" are slopes. The parameters we can change in DesQ model are various but we have focused on differing rainfall and land use patterns. The principle advantage is that we can use the model to evaluate the impact of the land use changes that happened in the past on the present surface runoff characteristics. The model was used for scenario simulations of hypothetical events. The quantity of rainfall (H) used in the model is 100 mm.

RESULT AND DISCUSSION

The land use changes, which occurred over the last eight decades in the upper reaches of the Krupá River catchment, are analysed. Aerial photographs and databases from archival data containing cadastral units were used to show these changes. Forest boundaries were changed, most recognisably after The Second World War. In 1936, the forest area covered only 2619 ha compared to 4393 ha in 2002 in the Krupá River catchment. The following Figure 2 illustrates orthorectified aerial photos of the upper reaches from 1936 and 2002.

Figures 3 and 4 present the calculations based on the values obtained from CN curves for both the forest area and the agricultural land in the upper reaches of Krupá River catchment in 1930 and in 2002. The lowest values are reached on plots with good hydrological soil characteristics, and where

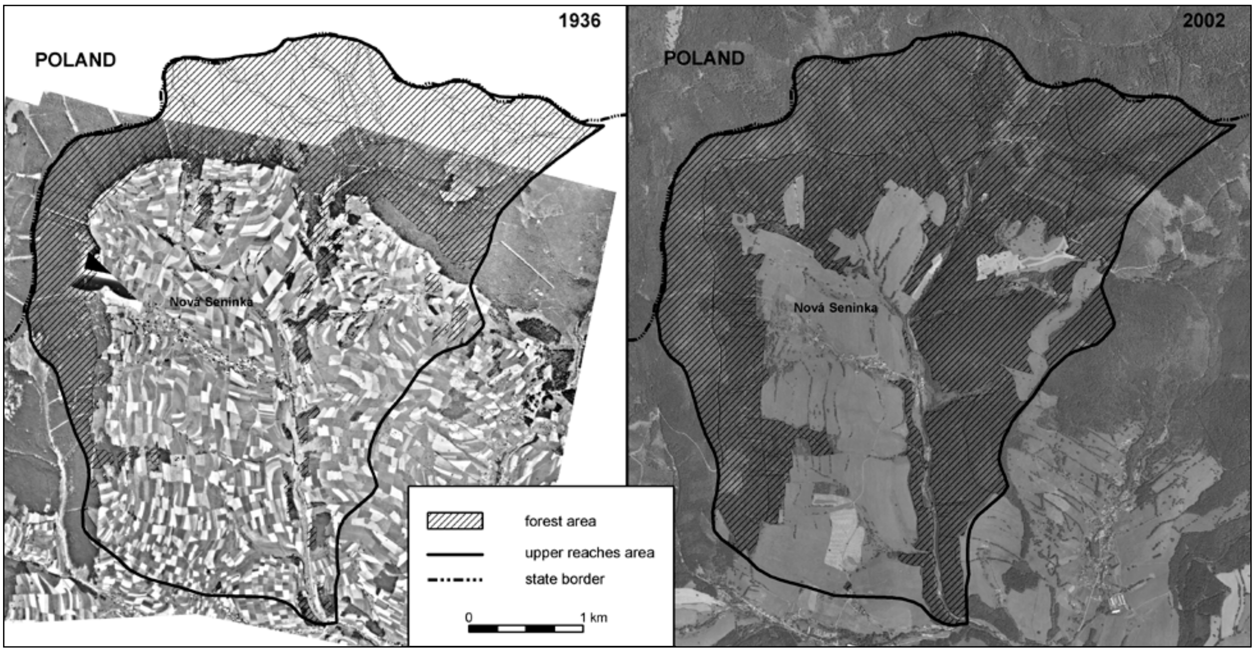

Figure 2. Forest areas in the upper reaches of the Krupá River catchment (from 1936 and 2002)

for example forests, meadows, and pastures are present. Such plots have high retention features and the lowest surface runoff values. Moreover, the CN curves are used for the calculations of other hydrological characteristics in the individual subcatchments of the upper reaches of the Krupá River in the years 1930 and 2002.

A significant land-use change can be observed which took place in the last 70 years in the upper reaches of the Krupá River catchment. Especially, the area of forests increased, in particular on the left side of the catchment. In 1930, the area was intensively agriculturally managed, the arable land covered almost 50%, and these facts impacted the direct runoff values which ranged between 31–45 mm (Table 2). In contrast to the year 1930, no arable land was present in the area in 2002, and thus the direct runoff values reached much

Table 2. Hydrological characteristics calculated by CN methods in 1930 (potential retention – *A* (mm), direct runoff – *Ho* (mm), direct runoff volume – *Oph* (m^3))

Subcatchment	Area (ha)	1930				
		CN	*A* (mm)	*Ho* (mm)	*Oph* (m^3)	*Oph*/km^2 (m^3/km^2)
12000	272.2	71	103.7	34.3	93 422	34 321
12001	124.3	71	103.7	34.3	42 661	34 321
12002	119.6	69	114.1	31.1	37 240	31 137
12003	18.8	74	89.2	39.4	7 403	39 376
12004	60.7	72	98.8	36.0	21 833	35 969
12005	108.6	73	93.9	37.7	40 892	37 653
12006	296.9	74	89.2	39.4	116 908	39 376
12007	178.1	75	84.7	41.1	73 265	41 137
12008	56	72	98.8	36.0	20 142	35 969
12009	110	76	80.2	42.9	47 231	42 937
12010	175.2	77	75.9	44.8	78 449	44 777

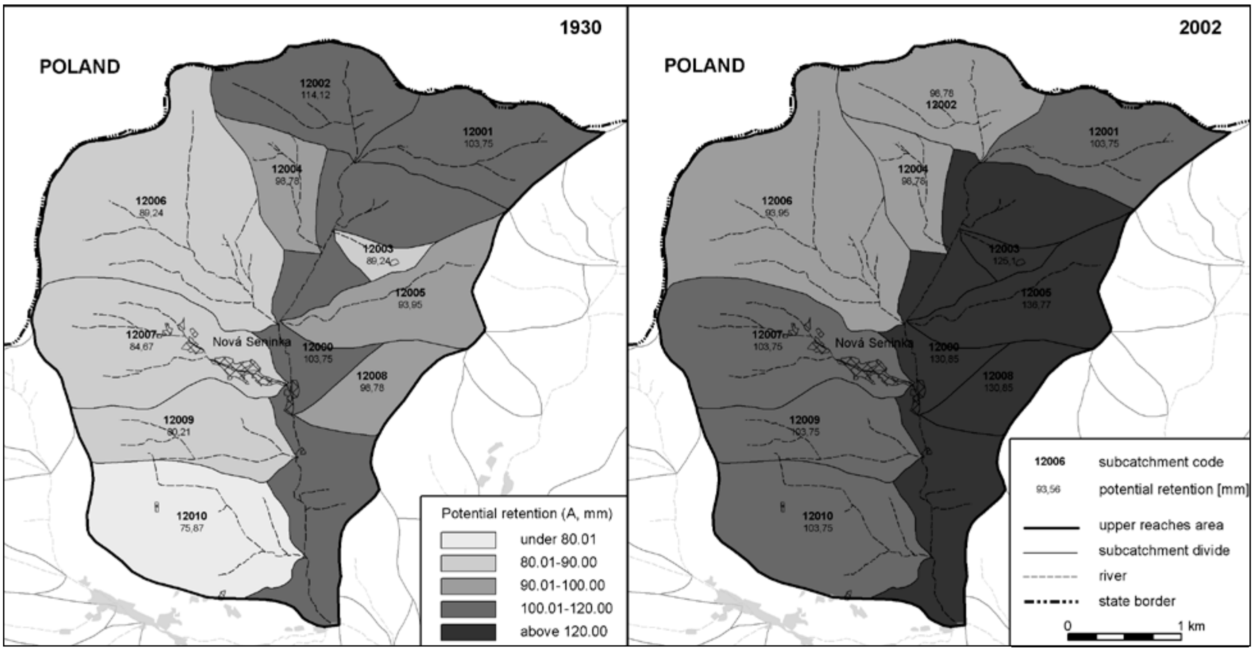

Figure 3. Potential retention (*A* (mm)) in individual subcatchments (from 1930 and 2002)

more favourable values ranging from 26 to 37 mm (Table 3). In 1930, the catchment area No. 12010 had the worst hydrological characteristics. In 2002, a majority of once arable land in the same catchment was transformed into permanent grass growths and forests, and, consequently, the direct runoff declined by 10 mm. However, this particular catchment represents one of those with a rather high *Ho*. The reason for such a situation may be the HSP category, when a hydrological group of soils dropped from B category (in 1930 – arable land) to a less favourable category C (forested area in 2002).

To calculate the maximum (peak) discharge Q_{max}, flood wave volume W_{pvt}, with a model precipitation volume 100 mm using DesQ model, the upper reaches of the Krupá River were divided into 11 partial subcatchments. The data obtained

Table 3. Hydrological characteristics calculated by CN methods in 2002 (potential retention – *A* (mm), direct runoff – *Ho* (mm), direct runoff volume – *Oph* (m^3))

Subcatchment	Area (ha)	2002				
		CN	*A* (mm)	*Ho* (mm)	*Oph* (m^3)	*Oph*/km^2 (m^3/km^2)
12000	272.2	66	130.8	26.6	72 491	26 632
12001	124.3	71	1037	34.3	42 661	34 321
12002	119.6	72	98.8	36.0	43 018	35 969
12003	18.8	67	125.1	28.1	5 282	28 098
12004	60.7	72	98.8	36.0	21 833	35 969
12005	108.6	65	136.8	25.2	27 368	25 201
12006	296.9	73	93.9	37.7	111 793	37 653
12007	178.1	71	103.7	34.3	61 126	34 321
12008	56	66	130.8	26.6	14 914	26 632
12009	110	71	103.7	34.3	37 753	34 321
12010	175.2	71	103.7	34.3	60 131	34 321

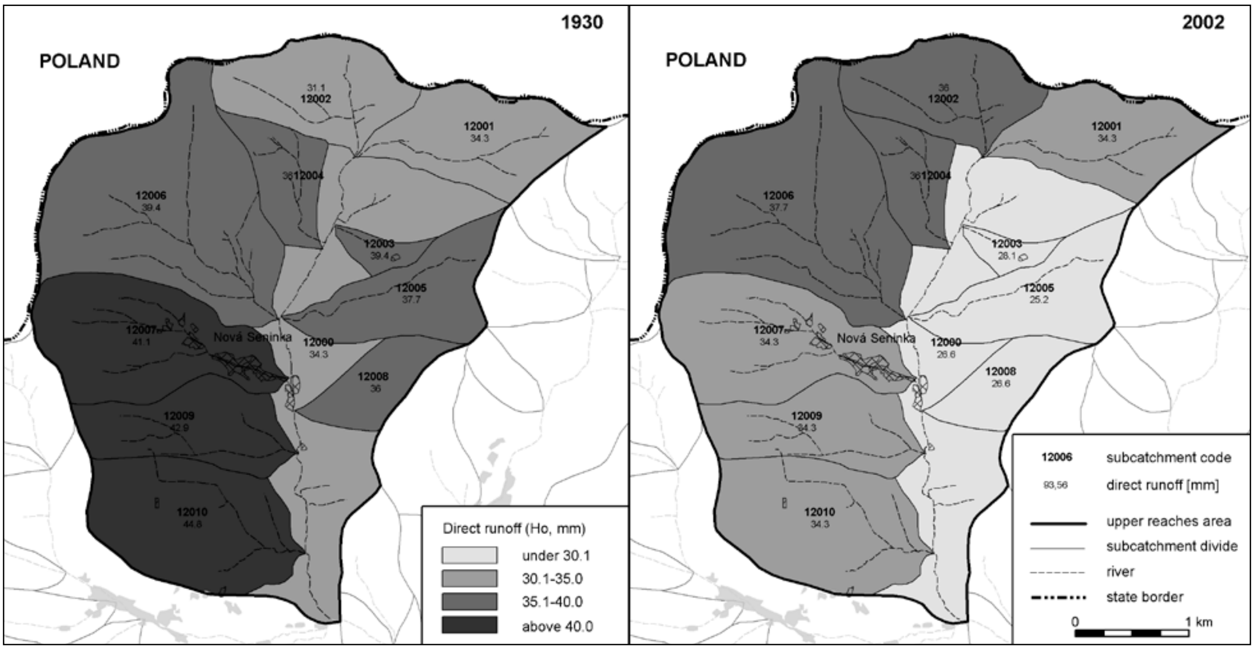

Figure 4. Direct runoff (*Ho* (mm)) in individual subchatchments (from 1930 and 2002)

from the DesQ model for the years 1930 and 2002 from each subcatchment are given in Tables 4 and 5. Generally, it can be concluded that the catchments with high values of CN curves show the least favourable hydrological characteristics. The maximum discharge in all catchments is lower in 2002 than that in 1930. The only exception can be observed in the northernmost catchments No. 12002 and 12004. In the catchment No. 12002, the discharge even increased by more than 1 m^3/s in 2002 in comparison with the values of 1930.

The factors for both the set and specific conditions in a certain site play their crucial role in the initial part of a flood event. Some of them, such as the inclination, soil characteristics, and the amount of precipitation cannot be influenced. But

Table 4. Hydrological characteristics calculated by DesQ model in individual subcatchments in 1930 (computed duration of rainstorm – T (min), hydrograph volume – W_{pvt} (m^3), maximum rainstrorm discharge – Q_{max} (m^3/s))

Subcatchments	Area (ha)	1930			
		CN_1930	Q_{max}	W_{pvt}	T
12000	272.2	71	16.3	92 200	341
12001	124.3	71	7.7	42 600	308
12002	119.6	69	5.3	37 400	373
12003	18.8	74	2.1	7 600	188
12004	60.7	72	3.7	21 300	302
12005	108.6	73	7.9	41 000	292
12006	296.9	74	15.6	115 000	427
12007	178.1	75	12.9	73 200	340
12008	56	72	4.4	20 300	246
12009	110	76	8.5	46 600	310
12010	175.2	77	10.7	79 000	419

Table 5. Hydrological characteristics calculated by DesQ model in individual subcatchments in 2002 (computed duration of rainstorm – T (min), hydrograph volume – W_{pvt} (m^3), maximum rainstrorm discharge – Q_{max} (m^3/s))

Subcatchments	Area (ha)	2002			
		CN	Q_{max}	W_{pvt}	T
12000	272.2	66	11.1	73 200	380
12001	124.3	71	7.8	43 300	308
12002	119.6	72	7.0	43 400	345
12003	18.8	67	1.2	5 380	213
12004	60.7	72	3.8	21 300	295
12005	108.6	65	4.5	27 600	331
12006	296.9	73	14.9	108 000	419
12007	178.1	71	10.5	62 500	332
12008	56	66	2.7	14 300	275
12009	110	71	7.0	37 800	304
12010	175.2	71	8.1	60 100	413

the land use of a certain area is one of the factors that has been changed during the development of such an area and has specifically impacted the landscape characteristics. In the research area, we could observe a significant change in the total area of forests during the time period between 1930 and the recent situation, which is typical for the border areas of the Czech Republic (Bičík 1998 or Kubeš & Mičková 2003). Also, a significant decline in the total area of arable soil can be observed, similar to the situation in other European regions (Lipský 1995; García-Ruiz *et al.* 1996 or Moreira *et al.* 2001). During the 70 years, the area of forests increased from 36% to 62%. In the 90´s of the 20th century, we can observe the trend of transforming arable land into permanent grass growths, also thanks to the subsidy programmes. The proportion of arable land in 1930 was rather high – reaching 49%.

The method of CN curves for the calculation of the water runoff volume from a particular catchment area was chosen for its apparent simplicity, and its low demand for the amount of entry data from the pilot area of Krupá. The method works with average values; on the other hand, the methodology is well developed for the area of the Czech Republic and as such is frequently used in practical research (Janeček *et al.* 1992). Moreover, the method can be efficiently used in GIS. With this method, we can determine both the direct runoff volume and maximum discharge in urbanised, agricultural, or forested catchments up to the approximate area of 10 km^2 (SCS 1975 in Kulhavý & Kovář 2000). However, it can be applied with some acceptable results even in the case of larger catchments (Hjelmfelt 1991 in Kulhavý & Kovář 2000). The suitability of the method for solving tasks set in the research can be corroborated by the fact that many hydrological models use this approach as one of the main methods (for example models DesQ or HEC). Using the method of CN curves and DesQ, we can conclude that the current land use (2002) leads to much favourable runoff characteristics of the area.

The entire research area was divided into 11 small subcatchments. Such fragmentation can help to localise more precisely the problematic plots, and to design measures to reduce the surface runoff. Moreover, the approached methodology shows that in small catchments also the land-use changes should be considered, together with the design of a sustainable strategy of flood control and introduction of well-timed measures for mitigation of flood-caused damage.

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