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THE IMPACT OF CHANGES IN LAND USE WITHIN A RIVER VALLEY ON THE CONDITIONS OF FORMATION OF FRESHETS

INTRODUCTION

The dramatic consequences of the floods, which took place in the South of Poland in the years 1997 and 1998, caused an increase of interest from the side of numerous research centres in the methods of hydraulic modelling of river runoff for purposes of forecasting of the probable reach of inundation in the river valleys. Practical application of models requires having an answer to the question of assessment of the spatial differentiation of the roughness coefficient values, necessary for the description of resistance to the water flow in the riverbed. We still lack ultimate solutions with this respect. In models with spatially distributed parameters the values of roughness coefficient are provided for the selected cross-sections of the valley. Most often, use is made of the tables, in which the values of the coefficients are ascribed to various hydrodynamic forms of the riverbed and of the land cover within its flood terraces.

In the determination of the parameter value insufficient attention is being paid to the issue of changes over time in the conditions of runoff, associated with the transformations in the land use structure. The values of the roughness coefficient are usually determined for the recent state. At the same time, the hydraulic models are being verified on the basis of the historical hydrological data. This may give rise to errors. In order to avoid them, it is necessary, before identifying the roughness coefficient, to perform an assessment of the transformations in the land cover structure.

The requirements of modelling of runoff signifies the necessity of analysing the spatial distribution of the particular land use forms. For this, selection of the characteristics describing the phenomenon is of key importance. Comparison of the changes in the total area of land use types, or in their percentage shares in the surface area of the flood terraces, is insufficient. It does not reflect the real scale of the phenomenon. The possibility of a detailed analysis of the phenomenon is provided only by the comparison of each of the land use forms separately. The GIS methods, ensuring the capacity of automatic processing of data and allowing for the introduction of the qualitatively new characteristics, are being applied in this kind of studies.

In order to illustrate the problem outlined, the example was used of the middle stretch of the valley of river Skora.[1] For this purpose the reach of the flood terraces was compared for 1948 and 1999. A map was presented of the changes in the spatial distribution of the roughness coefficient of Manning, illustrating the transformation of the conditions of the flood runoff in the 50-year period considered.

CHARACTERISATION OF THE STUDY AREA

Skora is a river of 48.6 km of length, belonging to the basin of Odra river. Three stretches can be distinguished along the course of the river, differing in terms of morphological and hydrographic features. The detailed analyses were carried out for the middle stretch (hydrologically controlled at the profiles of Zagrodno and Chojnów), of the length of 15.9 km. River valley cuts here deeply into the bedding. The bottom of the valley is flat, with the width between 250 and 450 m, and an average slope along the valley of 2.7‰. The natural relief of the valley is enriched additionally with the road embankments parallel to the river, and the flood protection walls of 2 km of length and up to 3 m of height.

The analysis of the morphological structure of the valley and of the archival materials concerning the reaches of the floods having occurred made it possible to determine the areas potentially threatened with flooding. They occupy the total surface of 5.5 sq. km.

The area considered has an agricultural character. At the same time, the land use in the valley is characterised by the concentration of the settlements within the valley. There are five villages within the stretch of the valley considered (15.9 km), and the town of Chojnów is located in its downstream part. A part of the structures are located on the flood terraces, which is conducive to the increase of the potential economic losses during the floods.

METHOD OF THE ASSESSMENT OF LAND USE CHANGES

The analysis of changes in the spatial structure of land use indispensable for the assessment of transformations in the runoff conditions on the flood terraces required:

— adaptation of the land use classification applicable for the determination of the Manning's roughness coefficient values;

— collection of the available sources of cartographic information on land use and elaboration of unified maps on its basis;

[1] A study was undertaken in 1998 at the Department of Hydrology of the Faculty of Geography and Regional Studies of the University of Warsaw, aiming at the elaboration of the mathematical model, simulating the inundation range in the middle reach of the Skora river (Soczyńska et al., 2001).

— elaboration of the maps of changes in the reach of individual classes of land use;

— determination of the quantitative characteristics describing the changes observed.

The classifications of the land use, adopted in the classical approaches do not coincide entirely with the characteristics of the bedding, which are necessary to assess the Manning's roughness coefficient. Besides, the accessible source maps contain limited amount of information. This meant that the number of categories had to be reduced to the one of the simplest map. Ultimately, nine categories were adopted: forests and tall shrubs (taller than 1 m), orchards, arable land, meadows (with domination of tall grasses), pastures (with domination of short grasses, forming a compact green), roads, wastelands, structures, and surface waters (including rivers and ponds).

In the assessment of the spatial use of the valley of Skora, all the available sources of cartographic information were used, such as topographic maps, panchromatic aerial photographs, aerial videos, and the results of field studies. They describe the state from various periods. At the same time they are characterised by a wide variety of the scope of information contained in them, as well as the manner of expressing it and legibility. They are elaborated on different scales and with different projections.

Utilisation of the source material gathered in the elaboration of the unified land use maps was associated with a number of problems, which were being solved with the GIS techniques. For this purpose the ILWIS v. 2.1 (The Integrated Land and Water Information System) software was used (Farifteh, 1996; Westen, Farifteh, 1997). The advantages of the software became visible already in the first phase of the analysis, connected with the necessity of bringing the source material to a single scale and a single projection. The ILWIS software makes it possible to match various information layers through their automatic transformation with the help of reference points. At the same time it is possible to make corrections in the touch-points by manual operations. The maps elaborated were made relative to the coordinate system of 1965.

A separate question is constituted by the interpretation of the source materials and the necessity of bringing the data to the unified categorisations. The software applied improved the legibility of the scanned images (including aerial photographs) through modification of pixel-based histograms (enhancement of contrast, assignment of different colours), and the possibility of enlarging them on the monitor screen. Besides, free aggregation of data is facilitated, with the adaptation of categorisations to the needs of classification for the maps of land use in the valley. Maps were elaborated in the vector format. Their conversion to the raster format, with the resolution of 4 sq. m, made the comparative analyses easier.

On this stage of the study, which concerned the assessment of changes in the spatial differentiation of the land use in the valley between 1948 and 1999, use was made of the possibility of overlaying the digital maps and of performing logical operations on them. Comparative analyses were performed for each of the land use classes in the valley separately. In this manner nine new maps were obtained, within which three differential categories were distinguished, namely the areas, on which a given land use category disappeared, persisted, or appeared.

Elaboration of the above outlined raster images made it possible to determine the quantitative characteristics of the observed changes in the land use in the valley. Calculations were facilitated by the function of the ILWIS software allowing for the automatic determination of histograms from the raster maps, and on this basis — for the determination of areas of the land use categories in question.

THE INFLUENCE OF THE SELECTION OF CHARACTERISTICS ON THE ASSESSMENT OF CHANGES IN THE LAND USE STRUCTURE OF THE VALLEY OF SKORA

During 50 years a evident transformation took place in the spatial structure of land use within the zone of the flood hazard. This fact can be noticed already through the comparison of the total areas of various land use forms in the years 1948 and 1999 (Fig. 1). These data, though, do not reflect entirely the phenomenon considered. What is important, namely, is the change in the spatial distribution of the particular categories of land use. Good example are the changes in the surface share of the meadows. During the time period

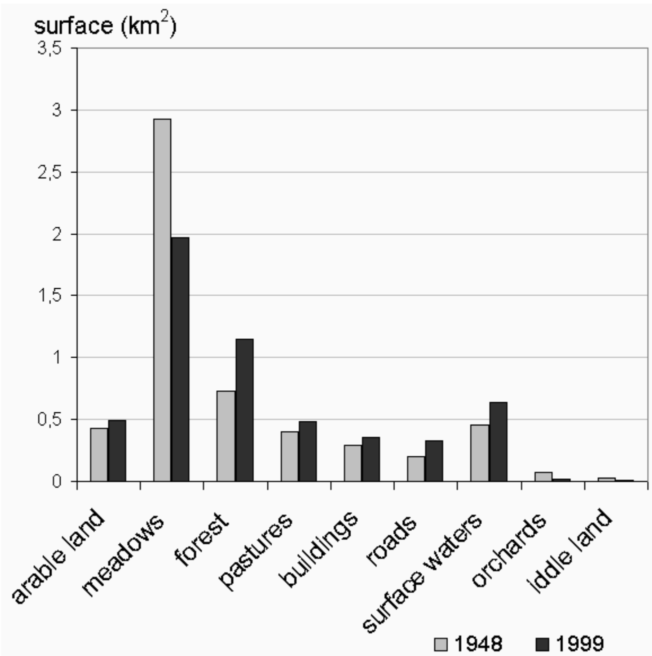

Fig. 1. Areas under particular land use forms in the zone of flood hazard of the Skora river valley in the years 1948 and 1999.

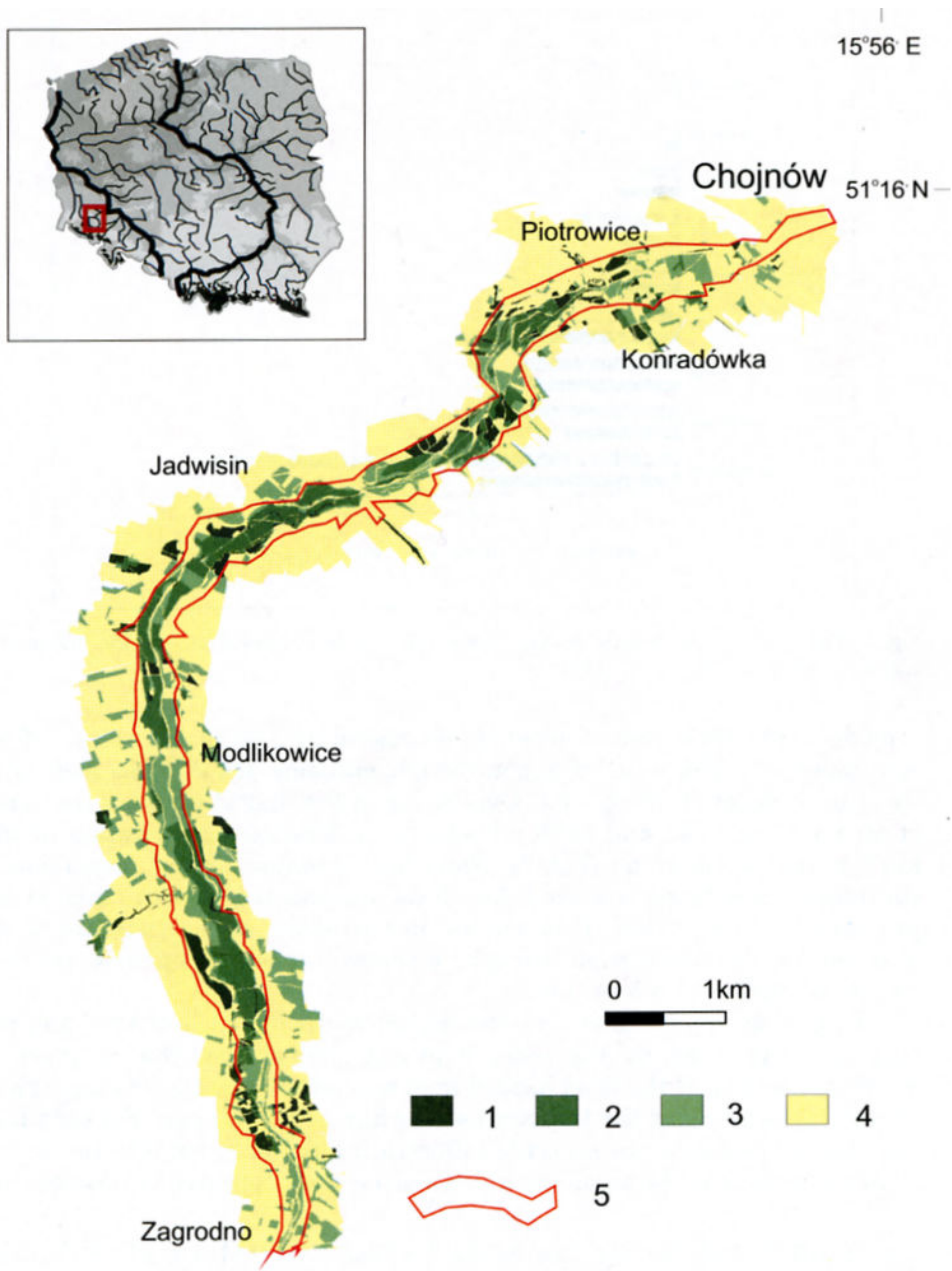

Fig. 2. Map of changes in the reach of meadows within the flood hazard zone of the valley of Skora in the years 1948 and 1999: 1 — new meadows; 2 — old meadows with no changes; 3 — areas of disappearance of meadows; 4 — area under study; 5 — the reach of the potential flood hazard zone.

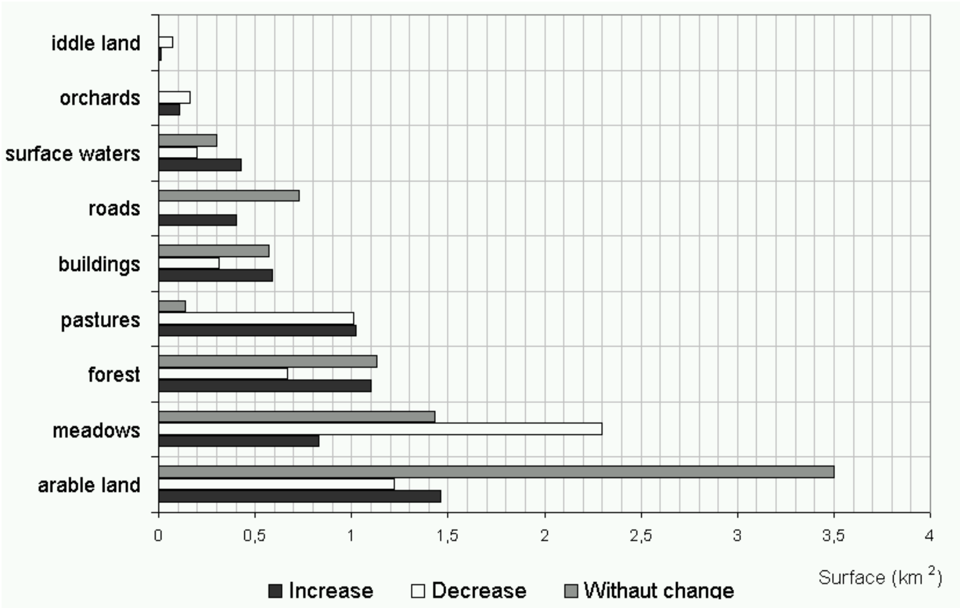

Fig. 3. The structure of changes in land use within the flood hazard zone of the Skora river valley in the years 1948 and 1999.

considered the total area of meadows decreased by 0.96 sq. km (17.4% of the zone analysed). The actual changes, though, encompassed the area more than two times bigger (1.98 sq. km). Overlaying of the digital maps of the reach of meadows in 1948 and 1999 allowed for a detailed consideration of this kind of transformations (Fig. 2). Nowadays, greater spatial dispersion of the meadows is being observed. Meadows disappeared over the area of approximately 1.48 sq. km. This applies, in particular, to the vicinities of the villages. At the same time, though, meadows appeared on new areas of the total surface of 0.5 sq. km.

The comparative analysis of the digital maps for each of the land use classes in the valley for the years 1948 and 1999 showed that as much as 43.3% of the area of the flood hazard zone was affected by the changes. Fig. 3 shows the structure of the transformations having taken place. For each land use class histograms are presented illustrating the area not affected by the changes, as well as the areas, on which a given class appeared or disappeared.

THE ASSESSMENT OF CHANGES IN THE SPATIAL DISTRIBUTION OF THE MANNING'S ROUGHNESS COEFFICIENT VALUES

The evaluation of the spatial differentiation of the parameter in question was carried out on the basis of the digital maps of land use in the valley, elaborated especially for this purpose, in accordance with the dependencies given in the literature. There are many publications (Chow, 1959; Byczkowski, 1979; Soczyńska, 1993; Wołoszyn, 1994; Ozga-Zielińska, Brzezińska, 1997), which provide tables of data, relating the coefficient in question to the characteristics of the land cover. The values of the coefficients usually vary for a given kind of surface within a wide range. This depends upon a number of factors. The most important factors include the nature of vegetation and the changes of its density during the growing season, as well as the thickness of the flowing layer of water (roughness usually decreases along with the increase of the water level). In the study the intervals of values, within which the parameter considered can vary, were accounted for. The mean value was adopted for the purposes of data processing.

The numerical maps of the spatial distribution of the roughness coefficient, describing the state from different periods, were acquired automatically through the passage from the descriptive attributes of the land use maps to the numerical values. This made it possible to carry out the comparative analyses. In this case the arithmetic operations performed between the numerical images were made use of. The reference unit taken was the grid cell of 2 × 2 m. By subtracting the values of the Manning's coefficient as of the year 1999 from that for the year 1948 the spatial structure of the coefficient changes was established. A large number of the obtained land plots motivated to the development of the synthetic map (Fig. 4). Similarly as in the case of analysis of changes in the land use structure three kinds of categories were distinguished. The first corresponded to the areas, on which changes have not been observed. The second — to the areas, where the values of the coefficient analysed increased, and the third — to those, in which they decreased.

THE CHANGES OF THE MANNING'S ROUGHNESS COEFFICIENT IN THE ZONE OF FLOOD HAZARD OF THE VALLEY OF SKORA

In 1948 the spatial differentiation of the value of Manning's roughness coefficient was small. The coefficient attained quite high values — between 0.09 and 0.11 — over the majority of the area of flood hazard. These values clearly decreased close to the dispersed settlement areas, where they varied between 0.012 and 0.06. At that time, the weighted average of the roughness coefficient value was 0.08, and it changed only slightly until 1999 (0.078). Yet, over this period distinct changes took place in the spatial distribution of the coefficient analysed. Nowadays, it has the pattern of a mosaic. Thus, for instance, low values of the coefficient appeared in the middle part of the area (close to the village threatened with floods). At the same time, the coefficient values increased (up to 0.20) in the northern part of the valley, this fact being connected with the appearance of a belt of shrubs and trees in this segment of the area.

The analyses performed indicate that in the period between 1948 and 1999 the Manning's roughness coefficient increased on 21% of the area and decreased

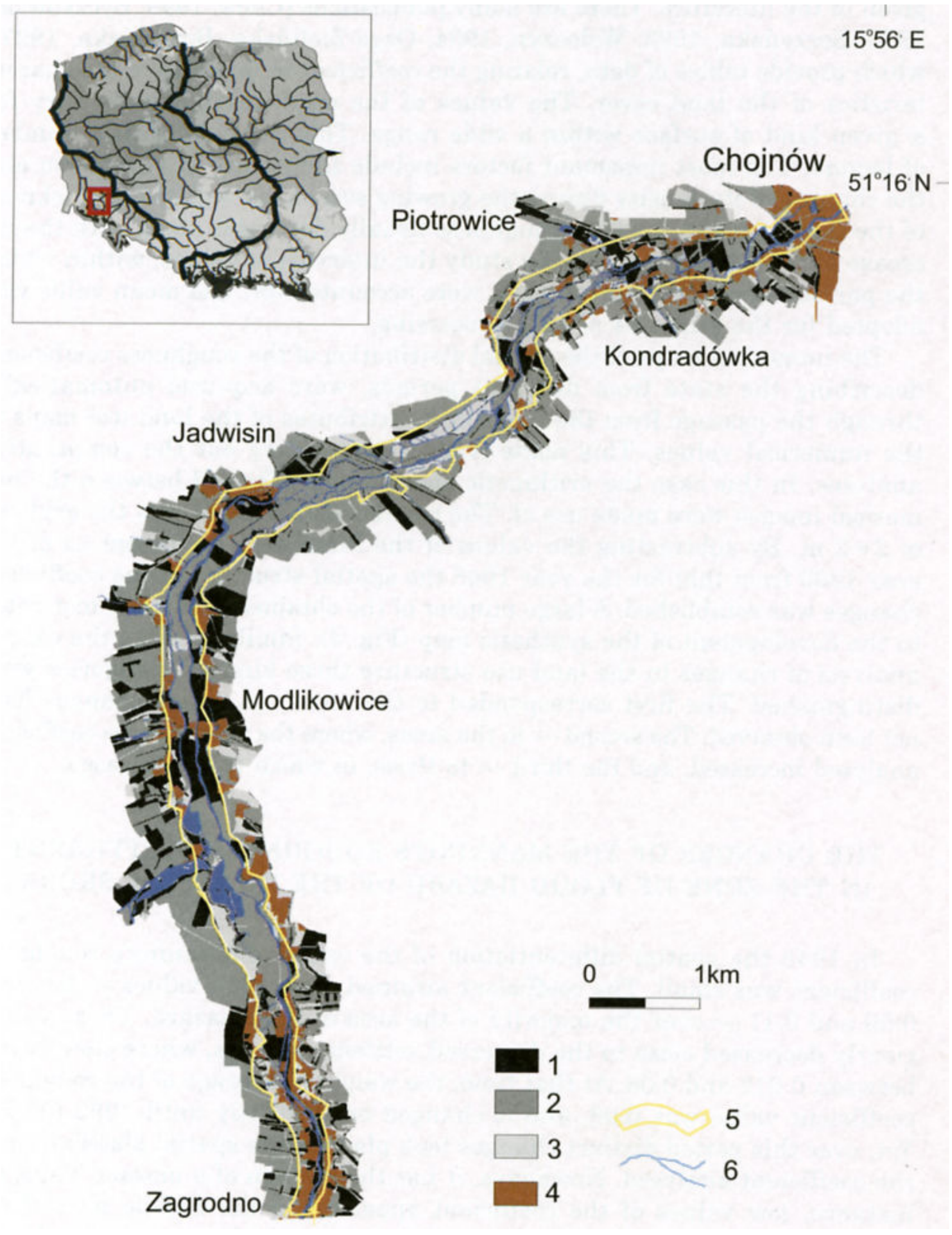

Fig. 4. Changes in the Manning's roughness coefficient within the flood hazard zone of the Skora river valley in the years 1948 and 1999: 1 — decrease of the coefficient value; 2 — no changes; 3 — increase of the coefficient value; 4 — structures; 5 — surface waters; 6 — the reach of the potential flood hazard zone.

on 25% of the area. The ratio of the surface of the transformed areas to the non-transformed ones is 0.86. The spatial structure of the changes described is shown on the map enclosed (Fig. 4).

CONCLUSIONS

The valley of middle Skora, chosen to provide the example for the considerations presented at the beginning, does not belong to the areas subject to strong anthropogenic pressure. It preserved its agricultural character over the 50 years in question. This might suggest that the changes of runoff conditions within the flood zone are small. Moreover, such a conclusion seems to be confirmed by the fact that the weighted average value of the Manning's roughness coefficient changed to an only slight degree (from 0.080 to 0.078). This image, though, is deceptive. The analysis conducted allowed for the indication of essential change in runoff conditions over 43.3% of the flood hazard zone. This is especially true for the areas located close to the villages and to the town. The absolute differences in the values of coefficient studied would most often exceed there 0.080. This might lead to the changes in the water levels close to the structures during flooding, reaching approximately 0.5 m. Although such phenomena are significant on a local scale, they are nevertheless essential from the point of view of assessment of flood hazard. The example presented confirms the necessity of analysing the changes in the spatial distribution of individual land use forms within the flood terraces before identifying and verifying the hydraulic models.

The observations made are of importance not just for the hydrological practice. The results presented in the paper provide yet another example for the influence exerted by the manner, in which data are processed, on the effects achieved. Provision and use of the mean or total values is often insufficient. When various characteristics are presented or used, they must be precisely interpreted. They must also be adequately adopted for the needs of the analysis, allowing for the reliable explanation of the problem.

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