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# The influence of morphological changes of small lowland river on discharge rate

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**Abstract:** *The influence of morphological changes of small lowland river on discharge rate.* The aim of the study was the comparison of the changes of cross-sections and longitudinal profile of the Mała river at the distance of 600 m. The paper presents the geometry changes of the river from field measurements made in 2013 in comparison with design assumptions from 1967 which were implemented in 1971. The four (available historical) cross-sections (hm 7+700, 7+800, 7+900, 8+000) and longitudinal profile (hm 7+700÷8+300) of the river were analysed and compared. The large scale of subsidence of the land surface on both banks was observed (even to 0.5 m). Probably it is the effect of peat shrinkage and mineralization processes of organic soils. The bottom of the Mała river was still located at the same altitude in sand deposits in the analysed period 1971–2013. The designed slope of bottom of the Mała river equals 0.7‰ (1967) and present slope (2013) was estimated to be around 1‰. The subsidence of peat layers on both river banks, changes in cross-sections' parameters (present irregular shapes in comparison with designed trapezoidal cross-sections) caused the reduction of cross-sectional area and water discharge of about 40–50% in comparison with parameters designed in 1967 and made in 1971.

*Key words*: lowland river, regulation of the river, sub-irrigation systems, discharge water flow

## INTRODUCTION

River valleys play very important role in the natural environment (Ilnicki, 2004, Oględcki and Pachuta, 2005, Ilnicki et al., 2010, Wyżga et al., 2013, Wyżga et al., 2014). The retention of huge amount of water in valleys has large influence on water regime (Żbikowski and Żelazo, 1993). The shape of riverbeds has big influence not only on hydrological conditions in the valley, but also on existence and development of flora and fauna. They are also habitats for many mammal species and aquatic birds due to occurrence of numerous plants, like: reeds and sedges, bushes and trees. The natural processes of forming and development of the rivers and valleys are results of many factors, like: water flow, transport with water some mineral and organic materials, debris transport and deposition (Żelazo and Popek 2002). The former river training was described as a technical regulation works were performed in order to prepare the rivers and valleys usually as a part of technical irrigation-drainage systems. Regulations of water conditions to meet plant water requirements is necessary for many places located near rivers (Ilnicki and Łoś, 1989). There are usually two types of systems: drainage, where rivers are receivers of drainage run-off water, and sub-irrigation systems, where the rivers are a direct source of water (Brandyk, 1990, Mioduszewski et al., 2010, Brandyk, 2011).

During the regulation works the basic morphological factors of the rivers, like: longitudinal profile, cross-sections, the slope of the bottom should be stable due to regulation constructions and consolidations (fixing) of the bottom, slope of the river banks (Żbikowski and Żelazo, 1993). The designed cross-sections of the river should fulfill technical as well as environmental requirements. The shape and dimensions of the river beds should provide designed discharge capacity, the elevation of open water level and stability of the banks and the bottom. The designed cross-sections during exploitation are changing due to some processes like erosion and sedimentation, the existence of the plants in the beds, animals inhabiting the beds, performing conservation works.

The aim of this paper is to analyse the changes of geometry and discharge of selected part of the lowland Mała river, used in formers time (XX century) for sub-irrigation system and compare it with design (1967) and made assumptions in 1971. The comparison of four cross-sections (every 100 m) and longitudinal profile (600 m long) were used to estimate present water flow conditions in the considered river.

## MATERIALS AND METHODS

The Mała river flows in Piaseczno district, in Góra Kalwaria and Konstancin Jeziorna communities (Mazovia Province – central part of Poland). The Mała river is the right-bank tributary of the Jeziorka river at the confluence in Konstancin-Jeziorna. The river flows from south to north, the length is around 19.7 km and the spring of the river is located nearby Krzaki Czaplinkowskie (Góra Kalwaria community). The lowland catchment (typical for this part of Poland) of the Mała river is estimated at 72.8 km$^2$ (Lenartowicz, 2007). The part of the valley, analysed in this paper, is characterised by very flat area, where upper layers (around 1 m deep) are peat soils and lower layers are sand deposits on the both sites of the river (Kaca, 1981, Brandyk, 1990, Bujakowski et al., 2014). In the vicinity of Solec village the Mała river was divided into two main channels in 1941–1943. The designe of subirrigation system for surroundings areas – Solec site was prepared in 1966–1967 and the Mała river was designed as a source of water for irrigation of peatlands by subirrigation system (Brożek, 1967, Tkaczewski, 1970). In 1967–1971 the project of sub-irrigation system was realized. The historical parameters of longitudinal profile (hm 7+700÷8+300) and four cross-sections (hm 7+700, 7+800, 7+900, 8+000) of Mała river were used from sub-irrigation project (Brożek, 1967). The first river channel served as irrigation ditch A and the second one was the main course bed of the Mała river (Fig. 1) which was designed for irrigation as well as for drainage of surrounding areas. The

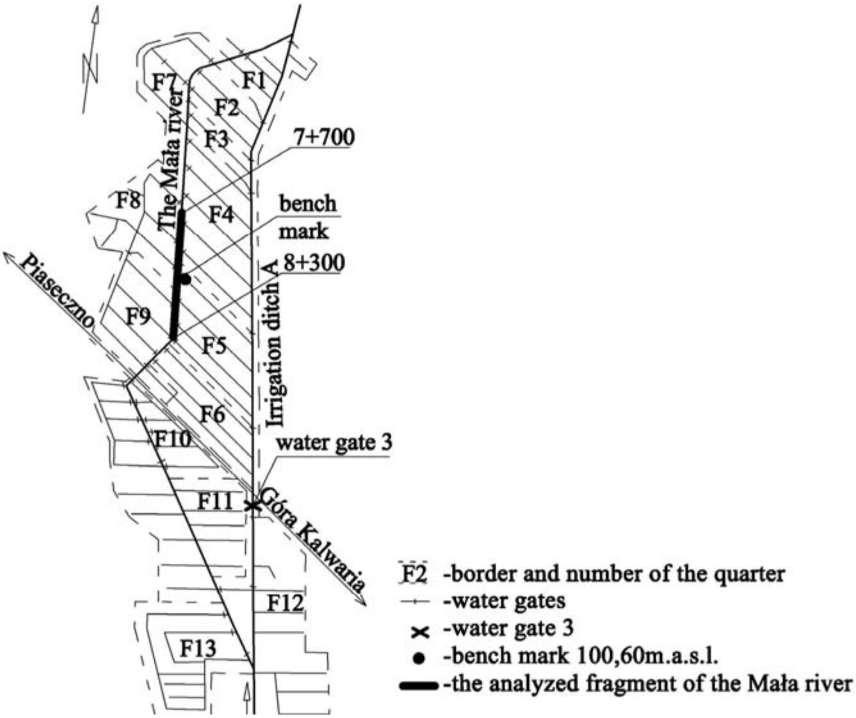


FIGURE 1. The scheme of the sub-irrigation system in Solec site (Kaca, 1981) with analysed part of the Mała river

design parameters in 1967 of cross-section of the Mała river were following: the width of the bottom 1.5–2.0 m, the depth 2.0–2.5 m and the slope 1 : 1.5. Nowadays the Mała river is maintained through conservation works performed by water community in Piaseczno. The last maintenance works were carried out in July-August 2012 and the following conservation works were done: mowing and moving of plants from the river, conservation the bottom of the river and removing of existing beaver dams. At present, the considered part of the Mała and the areas around the river belong to the Chojnowski Regional Park (it is a part of Mazovia Regional Parks) and it is also the area of Natura 2000 PHL 140055. Most of these areas on the left side of the river are under agricultural use (meadows and pastures), on the right side there are usually abandoned grassland.

Based on the project of sub-irrigation system from 1967, for the study four archival cross-sections (hm 7+700, 7+800, 7+900, 8+000) and longitudinal profile of the Mała river (hm 7+700÷8+300) were analysed. On 27–28 August 2013 the field measurements of mentioned cross-sections dimensions and longitudinal profile (600 m long) of the Mała river were measured in order to compare the designed (1967), made (1971) and present stages (2013) of analyzed part of the river. The values of coordinates of all points in cross-sections and longitudinal profile were calculated using land surveying method and the known of values of reference altitude point (100.60 m a.s.l.) located close to the analysed part of the Mała river (Fig. 1).

As it was mentioned before, the Mała river near Solec village flows through two types of soils: the top soils are mainly organic soils – moorsh and peat layers (reed-sedge) with medium degree of decomposition H6–H7 and the bottom of the river is located in sand deposits (Kaca, 1981, Brandyk, 1990). In order to estimate the actual depth of each type of soils along considered four cross-sections on the left bank, the depth of the peat deposit was examined using hand drill (on right bank of the river some organic and mineral materials after conservation works were accumulated).

The calculations of cross-sectional areas and flow velocity in analyzed cross-sections were performed, basing on field measurements of surface positions, water levels, and the shapes of cross-sections and using the following equation:

$$Q = u_s F \tag{1}$$

where:
$Q$ – flow intensity [$m^3 \cdot s^{-1}$];
$u_s$ – flow velocity [$m \cdot s^{-1}$];
$F$ – cross-section area [$m^2$].

Flow velocity ($u_s$) was calculated using the Chezy-Manning formula:

$$u_s = \frac{1}{n} R^{(2/3)} J^{(1/2)} \tag{2}$$

where:
$n$ – roughness coefficient [$m^{-1/3} \cdot s$];
$R$ – hydraulic radius [m];
$J$ – hydraulic slope [‰].

During calculation procedure of discharge of water flow of analysed part of Mała river in both cases (1971 and 2013) the same values of roughness coefficient ($n$ = 0.030 $m^{-1/3} \cdot s$) and hydraulic slope ($J$ = 1‰) were used.

## RESULTS

The designed and measured cross-sections (August 2013) of the analysed part of the Mała river (hm 7+700÷8+000) together with open water level are presented in Figure 2. On the left banks of the river the depths of the peat deposits were shown, on the top of right banks the mineral soil layers are observed as a result of conservation works performed in the channel of the river. In 1967 the designed parameters of cross-sections were following: slope of cross-section 1 : 1.5, the width of bottom 1.4 m, the medium depth 1.6–2.0 m and strengthening of the bottom by fascine hurdles (Brożek, 1967, Tkaczewski, 1970). Performed measurements in August 2013 showed that the both banks of the Mała river were subject to subsidence during last 46 years (1967–2013) due to peat mineralization (Ilnicki, 2002, Querner et al., 2012). It is especially visible on the left bank of the river (for example in cross-section hm 7+800 the subsidence

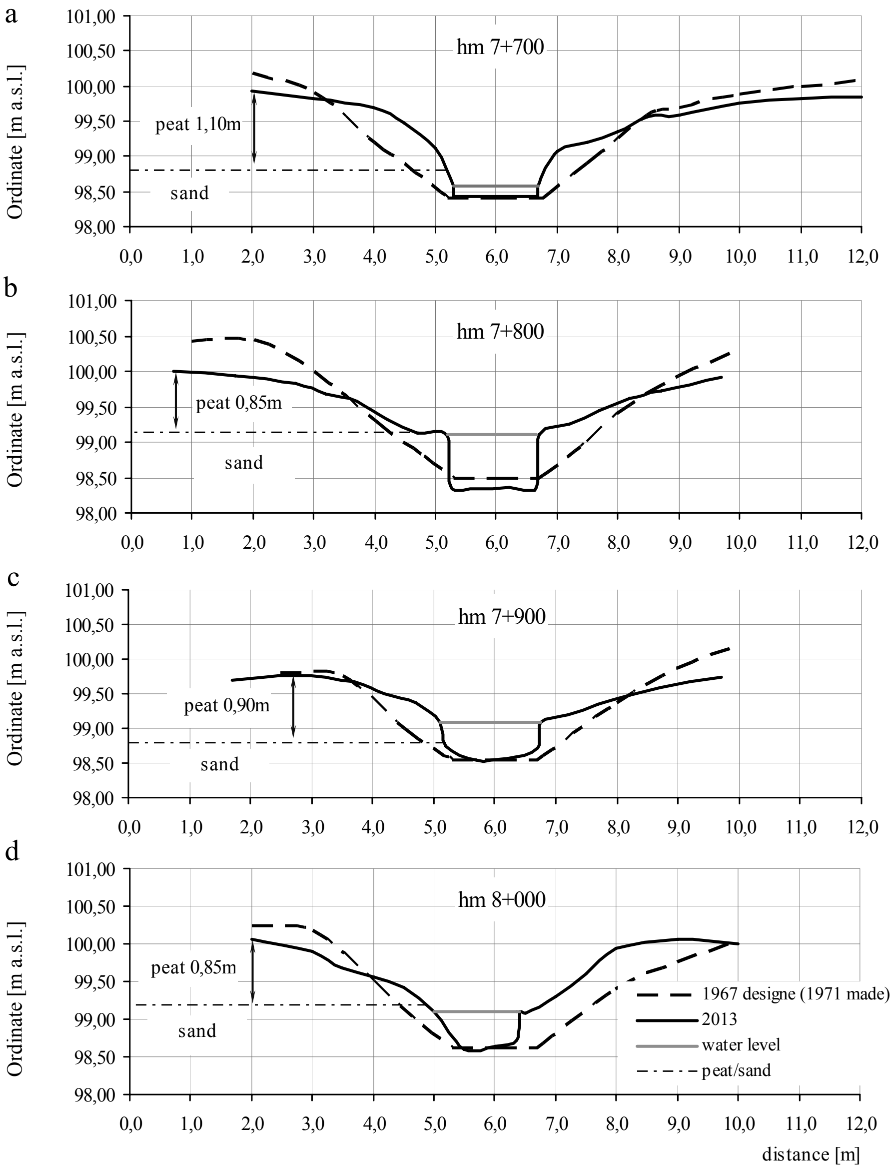


FIGURE 2. The cross-sections of the Mała river: a – hm 7+700, b – hm 7+800, c – hm 7+900, d – hm 8+000

is about 0.45 m (Fig. 2b). On the right bank of the river the subsidence process took also place, but it is quite difficult to estimate the scale of this process due to accumulation of some sand and plant remnants after conservation works in the river. The values of ordinates of both river banks in cross-sections with the ratio of subsidence in 1967–2013 are presented in Table 1.

TABLE 1. The values of ordinates of both bank the Mała river in analysed cross-sections with the ratio of surface subsidence of banks in analyzed years

| Year | Hectometre (Cross-section) | 7+700 (a) | 7+800 (b) | 7+900 (c) | 8+000 (d) |
|---|---|---|---|---|---|
| 1967 | Left bank [m a.s.l.] | 100.18 | 100.49 | 99.81 | 100.25 |
| 2013 | Left bank [m a.s.l.] | 99.92 | 99.99 | 99.70 | 100.05 |
| 1967–2013 | Difference [m] | 0.26 | 0.50 | 0.11 | 0.20 |
| 1967 | Right bank [m a.s.l.] | 100.08 | 100.30 | 100.20 | 100.05 |
| 2013 | Right bank [m a.s.l.] | 99.85 | 99.91 | 99.73 | 100.01 |
| 1967–2013 | Difference [m] | 0.23 | 0.39 | 0.47 | 0.04 |

From the data presented in Table 1 it can be concluded that the ratio of subsidence is higher on the left side in comparison with the right side of the river. The slope of scarps is regular and the scarps slided into the river, only in the bottom part of the cross-sections the vertical walls are observed due to fascine hurdles.

The longitudinal profile of the Mała river is presented in Figure 3 and the altitude values of bottom in selected cross-sections in 1967 and 2013 are presented in Table 2.

Based on data presented in the Table 2 it can be concluded that the changes in the ordinate values of bottom of the Mała river are negligible (without the cross-section at hm 7+800) where the differences were almost 0.15 m in the bottom between 1967 and 2013. Both river banks (left and right) are presented from 1967 and 2013 as well as the designed bottom (1967) and present (2013) and also open water level on 27 August 2013 (Fig. 3). Two beaver dams are also shown (hm 7+744 and 8+097), which have direct influence on the depth and level of water in the river. In the analysed section (hm 7+700÷8+000) of the Mała river the subsidence of the both banks were observed. In the upper part of the river (hm 8+100÷8+300) the values of coordinates are higher in 2013 in comparison with 1967 (specially on the right side of the river). It was caused by some mineral materials (sandy soils) coming from the bottom of the river af-

TABLE 2. The ordinate values of bottom of the river in selected cross-sections in 1967 and 2013 years

| Specification | Hectometre (Cross-section) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 7+700 (a) | 7+800 (b) | 7+900 (c) | 8+000 (d) | 8+100 (e) | 8+200 (f) | 8+300 (g) |
| 1967 | 98.41 | 98.48 | 98.55 | 98.62 | 98.68 | 98.76 | 98.82 |
| 2013 | 98.43 | 98.33 | 98.55 | 98.60 | 98.74 | 98.79 | 98.91 |
| Difference 1967–2013 [m] | –0.02 | 0.15 | 0.00 | 0.02 | –0.06 | –0.03 | –0.09 |

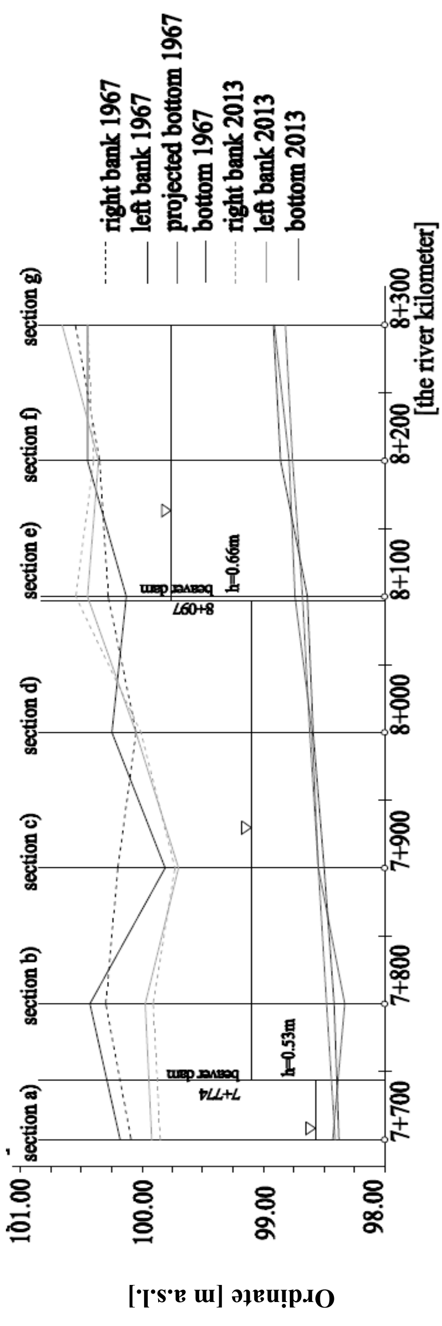


FIGURE 3. The designed (1967) and present (2013) longitudinal profiles of Mała river (hm 7+700÷8+300)

ter conservation works and materials after removing beaver dams. The designed slope of the bottom in 1967 was 0.7‰ and now the slope of the water level is estimated to be around 1‰.

Figure 4a presents the changes of cross-sectional area at different water levels in designed (1967), made (1971) and present (2013) selected cross-sections. At the higher water levels the decreasing (of about 1 $m^2$) of cross-sectional area in 2013 in comparison with 1971 was observed. These reductions can be explained by the subsidence of the banks and irregular shapes of the river in comparison to the project assumptions in 1967. The proportional reductions of the area ($\Delta F$) of the analysed cross-sections in 1971–2013 period are presented in Figure 4b. The biggest $\Delta F$ (even 30–50%) in cross-section area values were estimated by low water levels (98.75–99.25 m a.s.l.).

The characteristics of discharge are presented in Figure 5a. Generally the decreasing of discharge in 2013 was observed in comparison with 1971. At the low water levels the differences in discharge in analysed years (1971 and 2013) are negligible. At higher water levels the differences in discharge (at the same water level) can be estimated to be around 1.0–1.5 $m^3 \cdot s^{-1}$. The reduction of this parameter in comparison to 1971 in the analysed cross-sections is presented in Figure 5b.

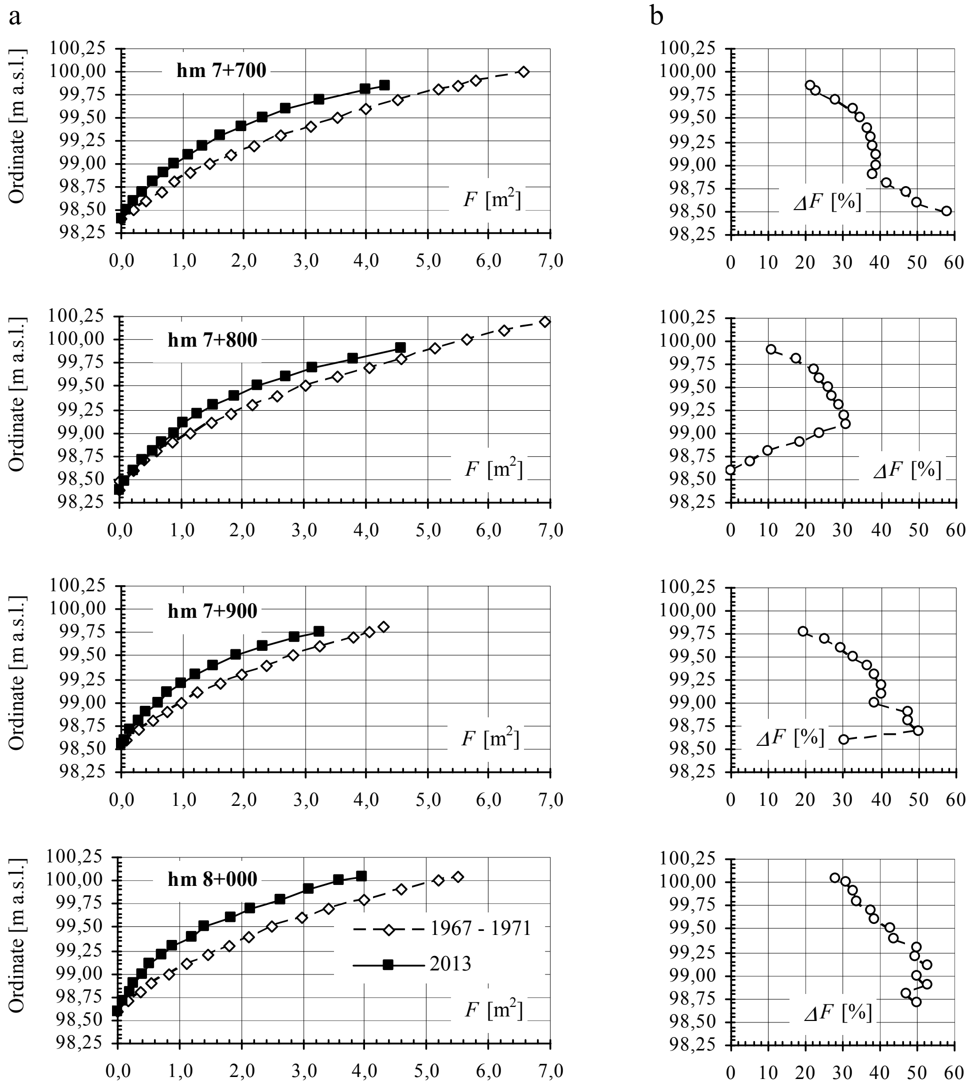


FIGURE 4. The changes of cross-sectional area $F$: a – at different water levels in 1971 and 2013 respectively; b – proportional reduction of cross-sectional area ($\Delta F$) in 2013 in comparison with 1971

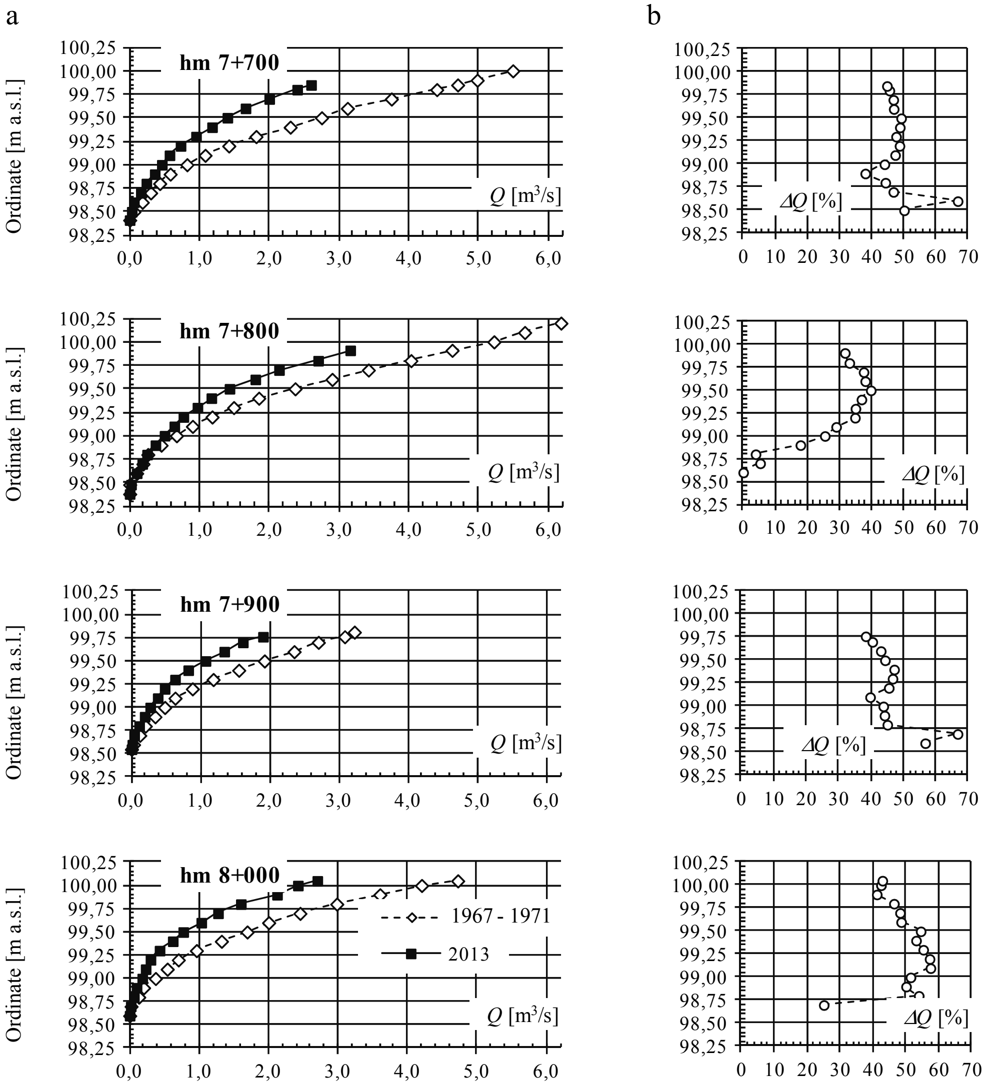


FIGURE 5. The changes of discharge flow ($Q$) in the analysed cross-sections: a – at different water level in 1971 and 2013 respectively; b – propotional reduction of discharge flow ($\Delta Q$) in 2013 in comparison with 1971

## CONCLUSIONS

1. The analysis of considered cross--sections (hm 7+700÷8+000) of the Mała river showed the decreasing of both banks altitude (even to 0.5 m) surrounding the river. It is specially visible on the left side of the river. In case of cross-sections (hm 8+100) the measured in 2013 banks altitude values were higher in comparison with projected values in 1967 due moving of beaver dams and leaving some mineral and organic materials on both analysed banks.
2. The shapes of present cross-sections (2013) are different from the trapezoidal designed in (1967) and from those realized from 1967 to 1971. The parameters of present irregular cross-sections (2013) are different from designed in 1967 and made in 1971.
3. The project slope of the bottom (1967) of the river was 0.7‰ and present slope of the water level in analysed part of the river is around 1‰.
4. The values of the bottom altitudes of selected part of the Mała river were changed negligibly in 1967–2013 period, only in cross-section (hm 7+800) the present bottom is lower of about 0.15 m in comparison with project bottom river in 1967.
5. The changes of geometry, which occurred in the analysed part of the Mała river in 1967–2013 (subsidence of both banks, irregular shapes of cross-sections), caused the reduction of cross-sectional area and water discharge at higher water level of about 40–50% in comparison with cross-sections designed in 1967.

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**Streszczenie:** *Wpływ zmian morfologii koryta małej rzeki nizinnej na jej przepustowość.* W pracy przedstawiono aktualne (2013) zmiany geometrii odcinka nizinnej rzeki Mała w stosunku do założeń projektowych (1967), zrealizowanych w 1971 roku. Analizą objęto cztery przekroje poprzeczne (hm 7+700, 7+800, 7+900, 8+000), dla których zachowały się materiały archiwalne oraz profil podłużny o długości 600 m (hm 7+700÷8+300). Przeprowadzone w 2013 roku badania terenowe wykazały znaczne obniżenie brzegów rzeki (nawet o około 0,5 m) w okresie 46 lat (osiadanie z racji procesów kurczenia i mineralizacji masy torfowej). Nie zaobserwowano natomiast znacznych zmian w rzędnych dna (podłoże piaszczyste). Projektowany spadek dna na analizowanym odcinku w 1967 roku wynosił 0,7‰, natomiast obecnie uległ nieco zwiększeniu i wynosi około 1‰. Pomimo przeprowadzanych okresowo prac konserwacyjnych analizowane przekroje poprzeczne obecnie różnią się swoim kształtem od projektowanych przekrojów trapezowych. Zmiany geometrii koryta na analizowanym odcinku rzeki wykazały również dużą zmienność pola powierzchni w poszczególnych przekrojach poprzecznych oraz zmniejszenie obecnie przepustowości analizowanego fragmentu rzeki o około 40–50% w stosunku do założeń projektowych z 1967 roku.

*Słowa kluczowe*: rzeka nizinna, regulacja rzek, systemy nawodnień podsiąkowych, natężenie przepływu

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