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STUDIES ON RIVERBED EVOLUTION ON THE NIDA RIVER AT THE PIŃCZÓW AND WIŚLICA GAUGING STATION

Summary

The long-term evolution of the river beds of Nida River in Pińczów and Wiślica gauging station as well as an analysis of the causes of significant cases of lowering of the bottom of stream beds are presented in the paper. The intensity of river bed evolution as a stochastic process is described with the use of a statistical model. The analysis of the intensity of the process of river bed erosion was conducted under the assumption that the observed long-term trend of the lowest annual water levels reflect the elevation of the river bottom in the same years. The recorded observations at the Pińczów and Wiślica gauging stations on the Nida River, covering over 70-year period of time, are analyzed. Observations of the variability in the studied bottom levels over the decades allow concluding that the great transformation of riverbeds occurred there. The observations and calculations show that in Pińczów multi-stream or meandering river bed changed into straight channel and the process of shallowing of the river bed appeared. At the Wiślica gauging station the process of riverbed erosion with the variable intensity was observed. The research shows that the causes of these changes observed in Pińczów and Wiślica are not natural, but rather of human activity.

Key words: riverbed evolution, river training, linear regression

INTRODUCTION

The river network in a catchment develops due to the action of flowing water and transport of material removed in the processes of erosion and denudation. An important characteristic of the fluvial system is its ability to self-regulate. The vertical and horizontal layout as well as the shape of stream cross-section undergo spatial changes in time as they adjust to the conditions forced by the intensity of flow of water and sediment, including bed load. The direct causes of the spatial changes of streams are the processes of erosion and deposition.

Under the conditions of geomorphological stability of river bed, at a proper time scale, the volumes of eroded and deposited sediment on a given stretch of the stream channel are comparable, and the stream bottom retains approximately the same elevation value. Also, there is no significant change to the shape of a perpendicular cross-section of the stream channel. In the case of horizontal instability of a streambed the processes of lateral erosion and deposition occur interchangeably in the consecutive stretches of the stream. The horizontal instability is often the deciding factor responsible for the change of the river channel type and the horizontal layout of a river.

Vertical instability causes the stream bed bottom to be raised or lowered. Under the conditions of instability, when the inflow of sediment is greater than the transport capability of a river, the process of aggradations occurs, raising the river bed bottom through deposition. If the inflow of sediment is smaller than the capability of a river to carry the sediment away, the process of degradation occurs, which is related to an erosional lowering of a river bed bottom.

The horizontal layout of river channel and its morphology are the result of the adjustment of the stream to the impact created by flow of water and sediment.

The purpose of this paper is to describe the long-term evolution of the Nida river bed at the Pińczów and Wiślica gauging stations as well as to conduct an analysis of the causes of sudden and significant cases of the lowering of the bottom of stream beds.

DESCRIPTION OF THE EXPERIMENTAL REACH AND AVAILABLE DATA

The Nida River, with a total length of 151.2 km, and the basin area of 3865 km^2, is the largest left-bank tributary of the Upper Vistula River. The outlet of Nida is located at the 175.4 km of the Vistula course. The sources of Nida are in the vicinity of the city of Szczekociny within the Płaskowyż Jędrzejowski at 268 m above sea level. The river is formed from the Biała Nida and Czarna Nida rivers. In Żerniki, Biała Nida joins its left-bank tributary, Czarna Nida, and changes its name to the Nida River. The total length of the hydrographic network in the Nida River basin network is 3900 km. The studied area is located in the mid- and lower sections of the Nida River (see Fig. 1).

In this area the river has sandy or muddy bottom and the average river slope below 2 ‰. On a number of tributaries of the Nida River water gates are located by which the water level in land reclamation system can be regulated. The number of hydrotechnical structures on the Nida River and the tributaries is estimated as more than 200. The reach downstream of Wiślica is continuously trained [Sustainable..., 2000].

Figure 1. The Nida River basin and locations of the analyzed gauging stations on the Nida River

The studies on river bed evolution were carried out for two gauging stations: Pińczów and Wiślica (Fig.1). For the Pinczów gauging station the period of 1947-2009 was analyzed; for the Wiślica gauging station the period of 1940-1991. Collection of observation data at Wiślica ceased in 1991 and the station was later removed. The sequences of data contain interval of discontinuity (1961-1970). This is due to the lack of recorded observations. However, the observation period of time guarantees sufficient amount of data for a good analysis of variability of the river bottom level over time. Moreover, evaluation of the process and progress of river bottom erosion, based on data from past years documents the changes that occurred in the river channel.

All analyzed sequences of annual low stages were adjusted to reflect the changes of the gauge zero level of river gauges and the changes of gauging station locations that occurred over the years.

In order to verify the results of calculations based on the minimum annual water stages, the data of geodetic measurements at given cross-sections of a river bed during the years were studies as well.

At the Pińczów gauging station the 1977, 1983, 1993 and 2003 geodetic measurements were analysed, at the Wiślica gauging station the analysis was made for the 1958, 1971 and 1989 geodetic cross-sections.

METHODS OF RIVERBED CHANGES ANALYSIS AND VERIFICATION

The intensity of river bed erosion as a stochastic process is described herewith with the use of a statistical model.

The analysis was conducted under the assumption that the observed long-term trend of the annual minimum water levels reflects the level of the stream bottom in the same years [Punzet and Czulak, 1994]. This assumption is valid under the condition that the annual minimum discharges do not vary significantly over time [Łapuszek, 1999].

The research of the process of river bed erosion at the Pińczów and Wiślica cross-sections on the Nida River was possible to be made because data were available. Specifically, over 50-year long sequences of annual minimum river stages were available in the 1940-2009 hydrological yearbooks.

Some sequences of data contain points or intervals of discontinuity. This is due to the lack of published water level data or the lack of recorded observations. Changes of the zero gauge level were taken into account while creating graphs of the annual minimum river stages.

The obtained multi-annual sequences of annual minimum river levels were divided into time intervals, for which lines of trend can be defined. These functions specify the stream bottom level at time T and show the lowering of the bottom of the stream. They are expressed in the general form [Łapuszek, 1999]:

$$H_d = H_z + H_i(T) \text{ [m a. s. l.]} \tag{1}$$

where:

H_d – averaged stream bottom level in year T [m a.s.l.],
H_z – assumed reference level [m a.s.l.],
T – year of observation,
$H_i(T)$ – an approximating function for the i-th time interval.

In a particular gauging station the data series for each specified time interval is approximated by linear interpolation. The investigated function $H_i(T)$ illustrates the main trend of level changes in the gauging station cross-section over a long time period [Łapuszek, 1999]:

$$H_i(T) = aT + b \tag{2}$$

where a, b are estimated parameters. The values of the coefficients a and b of the line of regression are obtained by using the method of least squares.

Verification of the obtained functions, describing the intensity of erosion processes in the researched river beds, was based on the analysis of the recorded data representing river bottom level changes over decades. The data were obtained by geodetic measurements at certain cross-sections of the rivers.

THE RESULTS OF COMPUTATIONS

The results of calculations performed for the Pińczów and the Wiślica gauging stations of the Nida River are shown in Fig. 2 and Fig. 3, respectively. The results allow to analyze the variability of erosion processes during time intervals of the research period. It should be emphasized that the values of the intensity of river bottom level changes refer to the cross-sections associated with gauging station sites and their immediate neighborhoods.

In the case of Pinczów gauging station the data series of 1947-2009 was divided into three time intervals: 1947-1970, 1971-1994, 1995-2009. The relation between water stage (H) and time (T) is given by equation $H_i(T)$,determined for each time interval i =1, 2, 3 (Fig. 2). The intensity of changes in time is expressed by the slope coefficient of the $H_i(T)$ regression.

In the Wiślica gauging station the series of 1947-2009 water levels was analysed. The interval of discontinuity of data series occurred from 1961 till 1970. The data series for computation was divided into two time intervals: 1940-1960 and 1971-1991. The calculation results of the intensity of river bed erosion processes over the years at the Wiślica gauging station are presented in Fig.3.

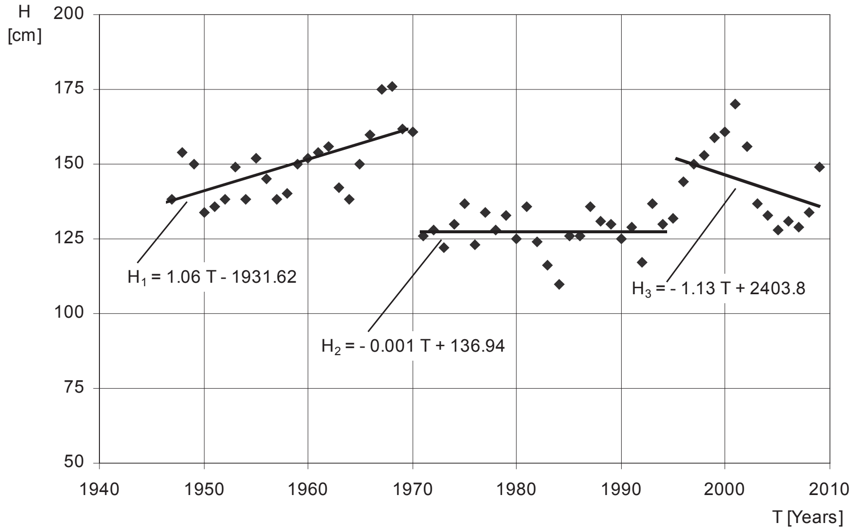

Figure 2. Annual minimum water stages and linear regression lines at the Pińczów cross-section

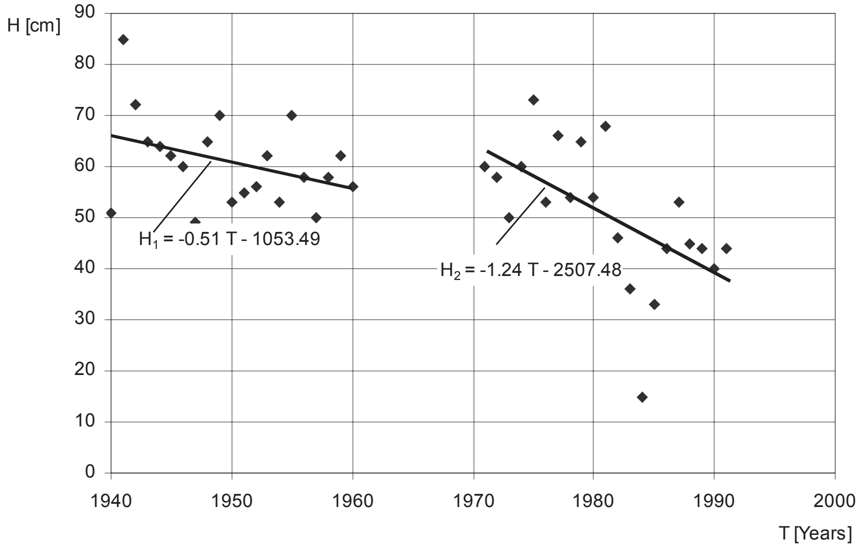

Figure 3. Annual minimum water stages and linear regressions at the Wiślica gauging station

RESULTS ANALYSIS AND VERIFICATION

Observations of the variability of minimum annual water stages in the studied gauging stations of Nida River over the decades, allow concluding that the process of erosion and deposition occurred with different intensity.

The Nida River in the studied course was a typical meandering river till the end of 15th century. Land use changes in this area by developing agriculture and deforestation caused the process of meandering decaying.

Widening and shallowing of the channel has been observed throughout the river course close to the Pińczów gauging station. This process was stopped as a result of river training activities which were executed in the end of the 19th century. In the years 1950-1970 the process of riverbed deposition in Pińczów was observed as the effect of the river training on the tributaries of the Nida River. The effects of the works were accelerating high flows from the valley directly to the river what resulted in the transport of large amounts of sediment directly to the Nida River. In the 70s of the 20th century another river training was executed. The river channel was removed into a new one. Then the channel was in equilibrium till the beginning of 80-90s, when the process of shallowing the channel appeared again. For this reason, the river training was carried out again in 1995 [The Regional Water Management Board in Kraków].

At the Wiślica gauging station, located in the low part of the Nida course, slight erosion was observed during the period of 1940-1960. In 1971-1991, the process of riverbed erosion was intensive, caused by river training carried out in 1976 on the reach from km 23.480 to km 25.568 of the river course.

Generally, these processes caused lowering of the river bottom over the research period at the Wiślica gauging station of about 30 cm. There are two causes of this variability. The first is river training, like for example bank protection works. The second one is very high water levels, including flood levels, with very high peak discharges, which occurred periodically, even every couple of years. These high water levels and peak discharges additionally cause moving the sand stored in the river bed.

Verification of the obtained functions, describing the intensity of erosion processes in the researched river beds, was based on the analysis of the recorded data representing river bottom level changes observed over decades. The data were obtained by geodetic measurements at given cross-sections of a river bed. Average annual lowering of the river bottom was determined for the established time intervals based on the observed changes of the river bed levels provided by the data sets spanning many years.

The selection of cross-sections chosen for the purposes of verification depended on:

– a possibility of verifying a function for a given time interval,

– a possibility of obtaining data for the cross-section,

– the magnitude of change in elevation of the river bottom that occurred, so that the difference would be clearly distinguishable.

The values of an average annual lowering of a river bed so obtained were compared with the values of the slope coefficients of the functions $H_i(T)$ describing the intensity of erosion changes of a river bed.

The verification was done for time intervals for which obtaining of appropriate geodetic cross-sections was possible. Figs. 4 and 5 show the changes in the river bed geometry of the Nida River at the Pińczów and Wiślica gauging stations, respectively. In Table 1 average annual lowering of the river bottom at selected gauging station cross-sections of the Nida River and the value river bottom lowering calculated from cross-sections (cm/year) are shown.

Comparison of the results shows that the slope values of the equation of regression are close to the values obtained by analysis of changes in geometry of the researched river beds. The verification has proven the correctness of the obtained results.

Table 1. Average annual lowering of the river bottom at selected cross-sections of the Nida River

Time interval	Formula for the intensity of river bottom erosion	River bottom lowering calculated from cross-sections [cm/year]
Gauging station: Pińczów		
1947-1970	$H_1 = 1.06\ T - 1931.6$	No data available
1971-1994	$H_2 = -\ 0.001\ T + 136.94$	No data available
1995-2009	$H_3 = -\ 1.13\ T + 2403.8$	years: 1993-2003: -1.0
Gauging station: Wiślica		
1940-1960	$H_1 = -0.51\ T - 1053.49$	No data available
1961-1970	No data available	years: 1958-1971: -0.5
1971-1991	$H_2 = -1.24\ T - 2507.48$	years: 1958-1971: -1.1

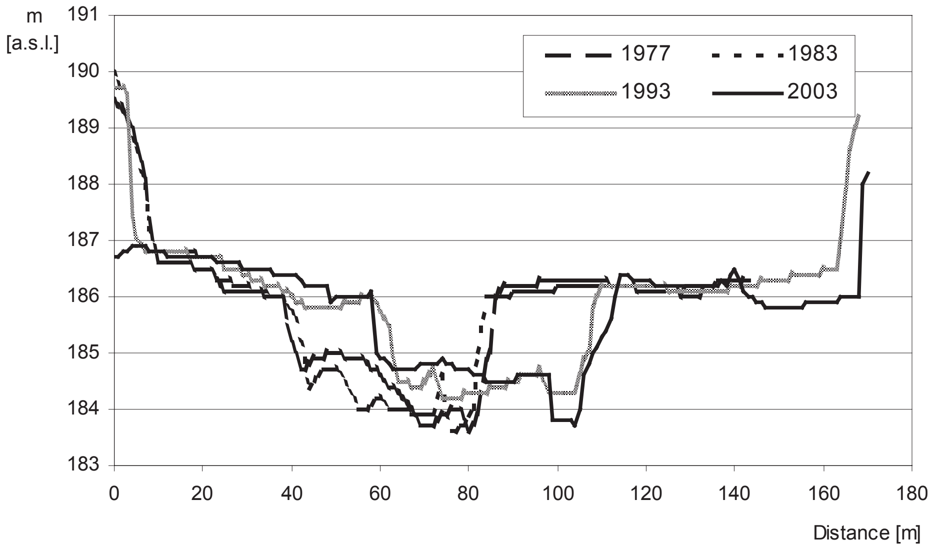

Figure 4. Channel geometry development in 1977-2003 at the Pińczów gauging station

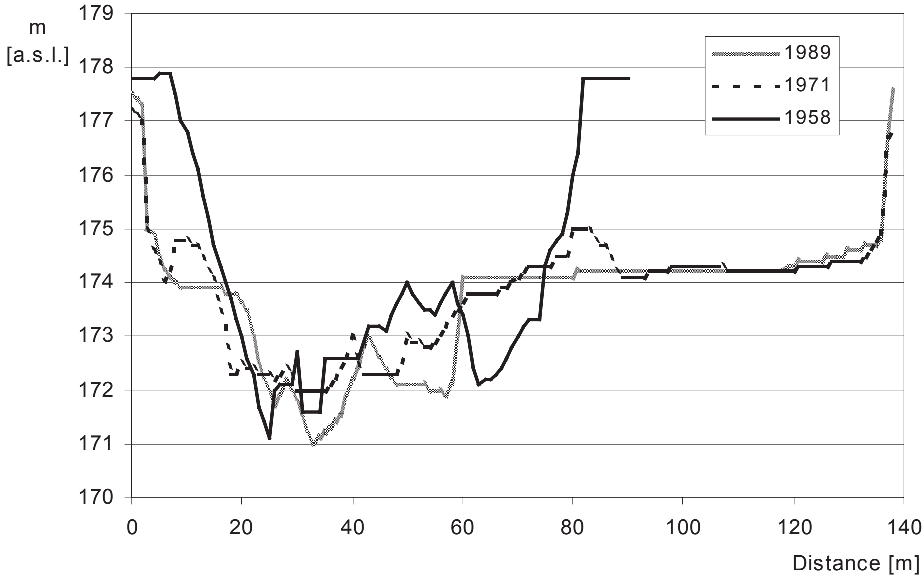

Figure 5. Channel geometry development in 1958-1989 at the Wiślica gauging station

CONCLUSIONS

The purpose of this paper is to present the trends and the intensity of changes in elevation of river bottoms at the Pińczów and Wiślica gauging stations on the Nida River, within the period of time of approximately 60 years. The research was based on the assumption that the changes of annual lowest river stages correspond to the changes of elevation of the river bottom. The regression equations showing the trends and the intensity of changes at the researched cross-sections were determined for specific time intervals. Verification of the obtained model changes of the researched river beds with respect to time was conducted by using independent material. The material included geodetic cross-sections of the river beds taken in different years. The verification involved comparing the real changes in elevation of the river bed recorded in particular time intervals with the changes calculated by linear regression. The verification proved the correctness of the obtained results. This implies that the method applied to determine the changes of elevation of riverbed over time is correct, and that it correctly identifies the trends and the intensity of riverbed evolution.

Observations and calculations have shown that in the lower course of the Nida River during the 20th century process of erosion and deposition occurred with the different intensity.

The horizontal layout of river bed changed. Multi-stream or meandering river bed changed into straight channel, and shallowing of river bed occurred like at the Pińczów gauging station. The research shows that the causes of these changes are not natural, but rather human activity. For the Pińczów cross-section, the rapid agriculture development and deforestation of the valley was the reason of riverbed evolution. The river training carried out on the most part of the Nida River tributaries affected the functioning of river bed system in the Pińczów gauging station.

The evaluation of continuing changes in the Nida River channel, and the identification of the causes of excessive evolution in this river bed, should be helpful in good management of the river bed systems. The evaluation of the river bed changes with respect to time may also become the basis for making forecasts of further progress of river bed evolution.

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