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DOES THE RIVER TRAINING MITIGATE FLOOD RISK ? CASE STUDY OF PIEDMONT SECTION OF VISTULA RIVER, SOUTHERN POLAND

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INTRODUCTION

Outline

Flood risk can be defined as an exposure to flooding of populated and developed valley bottoms. The size of that risk depends on the duration of overbankfull water stages, as well as on the related depth and extent of the water. A popular flood protection measure of river training is not always effective (Andrews, Burgess, 1991, Finlayson, 1991, Angelstam, Arnold, 1993, Gilvear, 1999, Łajczak, 2007, 2012). Erection of flood control embankments narrows down the river inundation zone thus increasing floodwater levels and its flow rates. Meanders are cut-off to let flood waves pass more quickly. River training leads to deepening and narrowing of river channels along their steep reaches, while along the more gradual reaches channels are shallowing and broadening through aggradation of the bed load carried (Brookes, 1990, Hey, 1996, Łajczak, 2007, 2012). River training shortens the time of flood waves concentration that travel faster along the river (Punzet ,1991, Łajczak, 2012). As a result of these effects river training has become a controversial method of flood risk control and may even be counterproductive (Cooper et al., 1987, Kajak, Okruszko, 1990, Andrews, Burgess, 1991, Finlayson, 1991, Angelstam, Arnold 1993, Kajak, 1993, Pinter, Heine, 2005, Łajczak, 2007, 2012). This leads to the question: does river training mitigate flood risk at all?

Aim of Study

The study objective is to perform a quantitative assessment of the current flood risk along the piedmont section of the River Vistula, southern Poland. The full length of the study section of the river has been trained using different methods. Much of the channel is deepening and has been narrowed to various extents, while some subreaches are shallowing. Three aspects of flood risk were analysed: the duration of inundation of the inter-embankment zone, the depth of the floodwater, and its horizontal reach. Variation of the flood wave speed was also considered.

Study Area

The 411-km long study section of the River Vistula runs across the Subcarpathian basins and the Polish Uplands. The river's mountain tributaries determine its hydrological regimen with a dominance of summer rain-induced floods. The mean discharge at the end of the section is 500 $m^3 s^{-1}$ while the maximum discharge reaches 7,700 $m^3 s^{-1}$. River training of this section began in the 1840s and was expedited after the catastrophic flood of 1884. To convert the river into a waterway with a deeper and narrower channel, as well as to reduce the risk of floods, the following measures were undertaken: the channel was shortened by cutting off meanders, stone groynes were erected perpendicular to the river banks and flood control embankments were built along the full length of the reach (Łajczak, 1995). The efforts peaked between 1890 and 1960 and ten large dams were put into operation within the reach's catchment area beginning in 1930s.

METHODS

The study analysed daily measurements of water level and rate of discharge made at 40 water-gauging stations on the section of the Vistula involved in the study. This data set, which started in the 19th century and continued until 2010, was obtained from the State Hydrological Survey. The progress of the river training was assessed using topographical maps published on average every 14 years over the last 230 years. Results of the training were assessed using level surveys performed at every water-gauging station approximately every 10 years starting at the beginning of the 20th century. The author's own fieldwork looking at the height of levees and of river banks along the river was also taken into account, which helped determined the length of deepened or shallowed subreaches.

Mean channel depth, Dm, and width, W, were assessed both at the present time and 100 years ago at each water gauging station. Other indicators analysed included: the W/Dm ratio, which expresses the compactness of the river channel; trends of change in minimum annual water stages, WSmin , at each water gauging station for the last one hundred years or longer which provides precise information about the rapidity of change of the river channel bottom height at water gauging stations; duration of inter-embankment zone flooding at water gauging stations in subsequent years, IN1[days.yr-1]; the number of flood events, IN2 [No.yr-1]. When flooding occurs, river discharge is greater than bankfull discharge, Qbf. The following characteristic discharge magnitudes [m3.s-1] were computed for all water gauging stations: mean discharge Qm, mean high discharge Qmh, and bankfull discharge Qbf.

RESULTS

Changes in channel geometry

The river training programme resulted in an overall shortening of the section by 15% and an average narrowing of the channel by a factor of two. This has led to its deepening, although this effect was also partly the result of gravel extraction in the river. The deepening process began in the mid-19th century in Krakow, where it reached a magnitude of more than 4 metres. The process of deepening the Vistula channel continued at a later stage also upstream and downstream of Kraków, but was less intense and there are even reaches spots where the river is shallowing. Prior to the training of the section its W/Dm ratios ranged from 40 to 400 along its course, while today they range from 5 to 156 and continue to shrink. These modifications to the channel geometry, in addition to a ten-fold average narrowing of the inundation zone, have caused an increased water level amplitude (up to 9 m) and rate of floodwater flow.

Reasons of changes during inundation time of the inter-embankment zone

The mechanism driving change during inundation of the inter-embankment zone may be explained by tendencies to an increase of Qbf discharge, which is a result of the change in river channel geometry. The change began upon the commencement of the river training efforts but can be documented since 1950s. Discharge of Qmh, despite long-term fluctuations, maintains roughly the same average level. Discharge of Qbf used to be similar to Qmh before river training, but has been growing ever since. The difference between the two values of river discharge is currently greater the more the channel has been shortened, deepened and narrowed. For example, in the Kraków area Qbf values increased by about a factor of three during the course of the 20th century, while in the longest still shallowing river channel section they only did by a factor of 1.45. The mean flood duration IN1 for the inter-embankment zone along the piedmont section of the Vistula is between 2 and 28 days per year. The IN1 values are smaller for the sub-sections of the river that have been deepened the most and have experienced the largest increase in bankfull discharge. Along the shallowing reaches, where the increase of the bankfull discharge has been negligible, the inter-embankment zone is flooded for longer than 10 days per year. The most frequent breaches of the embankments occur along reaches where the inter-embankment zone is flooded for a long time, which is well illustrated by the floods of May 2010 and May 2014. Currently inter-embankment zone flooding only occurs from May to October along all the piedmont section of the River Vistula. Flood waves caused by snow thaws are lower than summer flood waves. All types of floods must have occurred more frequently prior to the canalisation of the river, and this must have also been true of snowmelt floods. Floods must also have lasted longer, as evidenced by notes on the Great Flood of August 1813. The aforesaid changes in river channel geometry and discharge conditions lead to shorter inter-embankment zone flooding times and the elimination of flood risk in the spring season.

Changes in flood waves formation

The training of the piedmont section of the Vistula River has resulted in an ongoing increase in the concentration of flood waves, which have become shorter, but higher. As a result, flood wave travel time went down by 33% along the entire section and by 50% in Krakow vicinity during the 20th century. The increased concentration of flood waves in this section of the Vistula has led to a reduction of the flood wave volume due to increasing Qbf discharge values. The increase in Qbf discharge has to occur with a decrease in the volume of the upper part of the flood wave, i.e. the above bankfull water stage.

CONCLUSIONS

1. It is difficult to provide a simple assessment of the change in the flood risk along the piedmont section of the Vistula. Indeed, along the deepened channel reaches the duration of the inter-embankment zone inundation has been going down at the expense of larger flood waves, while along the most deepened reaches flood risk has been reduced to just the summer season. On the other hand, along shallowing reaches of the channel the flood plain inundation time has been extending while flood waves remained high.
2. In view of these facts an assessment of the current flood risk is mixed rather than clear-cut: certain training measures have reduced it, while others have increased it.
3. Another reason for an increased flood risk in the piedmont section of the Vistula valley is an increased speed of travel of the flood wave resulting in greater peaks of water stages in the inter-embankment zone during a shorter period of time. As a result, flood emergency responders have less time to secure the embankments.
4. Areas outside of the inter-embankment zone are generally safe from flooding. One exception involves areas along shallowing reaches near breached embankments.
5. These results contribute to the mainstream debate on the effectiveness of existing methods of river canalisation. These methods have been perceived as controversial and even counterproductive (Brookes, 1990, Kajak, Okruszko, 1990, Andrews, Burgess, 1991, Finlayson, 1991, Angelstam, Arnold, 1993, Hey, 1996, Łajczak, 2007, 2012). This article uses the case of the piedmont section of the Vistula River to prove the hypothesis

formulated by eg. Cooper et al. (1987) and Kajak (1993) with regards to other rivers where shallow channels (or even shallow reaches) tend to increase the flood risk.
6. In the light of the different aspects of flood risk associated with the piedmont section of the Vistula, the changes that have taken place over the last 100 years may be considered positive. In contrast to opinions expressed by some authors (eg. Andrews, Burgess, 1991, Finlayson, 1991, Angelstam, Arnold, 1993) the author considers training as a useful method on rivers with high levels of flood risk.
7. Alongside new large dams other realistic methods that could further reduce the flood risk include the expansion of the inter-embankment zone and creating polders for temporary retention of large quantities of floodwater (Łajczak, 2007, 2012).

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