Changes to the hydraulics of flood flows resulting from channel incision: Examples from Polish Carpathian rivers

Impacts de l'incision du chenal sur le fonctionnement hydraulique des rivières des Carpates polonaises au cours de crues

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RÉSUMÉ

Le creusement du lit des rivières peut résulter soit de l'incision du chenal soit d'une métamorphose fluviale. Puisque seul ce premier type de changement conduit à une augmentation de la capacité d'écoulement, un abaissement du niveau d'eau associé à un débit donné, plutôt qu'un abaissement du lit de la rivière, devrait être utilisé pour identifier le creusement du lit des rivières. Nous étudions dans la présente communication les impacts de l'incision du chenal sur le fonctionnement hydraulique des rivières des Carpates polonaises pendant les épisodes de crue. Alors que l'incision du chenal s'est accentuée dans les zones en aval de la rivière Dunajec, on peut observer une réduction importante de la fréquence des inondations dans certaines zones de la plaine inondable à l'amont de la rivière. Dans les rivières de haute énergie de la partie occidentale des montagnes, une ceinture de méandres incisés a été formée en raison de l'alternance de l'incision et la migration latérale du chenal. Il a résulté de cette phase d'incision un abaissement significatif du niveau d'eau pour tous les débits de crue et une augmentation de la vitesse des écoulements dans la plaine inondable, qui n'est pas très haute. Dans les rivières à faible énergie de la partie orientale des Carpates polonaises, latéralement stables pendant l'incision du lit, le niveau de l'eau a significativement baissé pour les crues de faible intensité. Le niveau de l'eau a également baissé pour les crues de forte intensité, mais de façon moins importante. La vitesse des écoulements s'est quant à elle considérablement amoindrie sur les plaines inondables, qui sont beaucoup plus hautes.

ABSTRACT

Channel deepening may result from either channel incision or river metamorphosis. Since only that first type of channel change leads to increased flow capacity of the channel, a lowering of water stage associated with a given discharge rather than a lowering of river bed should be used to identify channel incision. The impact of increasing river size and lateral channel stability on the hydraulic effects of channel incision was investigated in Polish Carpathian rivers. In the Dunajec River, the nominal amount of incision increased downstream, whereas the resultant reduction in the frequency of valley-floor inundation was greater in the upstream river course. In high-energy rivers of the western part of the Polish Carpathians, incised meander belts were formed due to the alternation of incision and lateral channel migration, resulting in substantially lowered stages for all flood discharges and increased velocity of the flows conveyed over the newly-formed, low-lying floodplains. In the low-energy rivers from the eastern part of the Polish Carpathians, laterally stable during channel incision, stages for low flood discharges lowered substantially and less so for high-magnitude floods; and velocity of the flows conveyed over the highly elevated floodplains has become considerably lower.

KEYWORDS

Channel incision; Flood flow hydraulics; Floodplain inundation; River adjustment; Polish Carpathians

1 INTRODUCTION

A loss of geomorphic dynamic equilibrium, manifested by fast-progressing channel incision throughout the 20th century, has been documented for numerous rivers worldwide (Darby, Simon, 1999). In some cases, the tendency was ascribed to a single or dominating causal factor such as in-channel gravel mining, construction of a dam reservoir, channel regulation or catchment reafforestation. More frequently though, the incision resulted from a range of factors limiting the availability of bed material for fluvial transport or increasing transport capacity of the river. In the Polish Carpathian rivers, the 20th-century rapid channel incision was associated with increased river transport capacity due to channelization, a decrease in catchment sediment supply, that followed land-use changes in mountain areas, or intense in-channel gravel mining (Wyżga, 2008). River incision has often been identified on the basis of change in the vertical position of the channel bed, reconstructed from repeated surveys of channel cross sections etc. However, this approach may lead to wrong recognition of incision as channel deepening may also occur in the course of river metamorphosis. Proper recognition of the phenomenon and its impact on the hydraulics of flood flows is especially important for implementation of effective remedial measures to stop and reverse river tendency to incise. This paper emphasises the need to distinguish between incision and channel deepening resulting from river metamorphosis induced by a change in sediment supply and investigates the impact of increasing river size and lateral channel stability on the hydraulic effects of channel incision in Polish Carpathian rivers.

2 CHANNEL DEEPENING AND CHANNEL INCISION

A lowering of minimum annual stage at gauging stations is typically used to assess the relative importance of channel incision along a river or within a particular region. However, a channel may deepen as a result of two different processes. First, bed lowering may occur due to river metamorphosis that is induced by a change from the bed-load to a suspended-load stream and leads to the transformation of the former wide, shallow and straight channel into a narrow, deep and sinuous one. If unconstricted, a river tends to adjust its channel to a reduced sediment supply through an increase in sinuosity and a reduction in channel slope with no significant change to channel conveyance and to the lateral and vertical extent of flood water on the valley floor at given discharges.

Channel incision occurs if a disrupted equilibrium between transport capacity of a river and its sediment load cannot be re-established through an increase in channel sinuosity and the resultant reduction in channel slope. This situation is typical of channelized rivers with reinforced channel banks and watercourses flowing in narrow, especially V-shaped valleys. In that case, bed degradation induced by excess power of flood flows will increase channel conveyance and the increase will lead to the lowering of water stages and a reduction in the lateral extent of inundation of the valley floor at given discharges. Therefore, the lowering of water stages at given discharges rather than the lowering of channel bed of a studied river should be considered an indicator of river incision.

3 VARIABILITY OF THE EFFECTS OF INCISION OF THE POLISH CARPATHIAN RIVERS WITH RIVER SIZE

Carpathian tributaries to the Vistula started to incise in their lower and middle courses at around the turn of the 20th-century. The lowering of their minimum annual stages at water-gauge stations indicates that over the last century the rivers incised by 1.3-3.8 m in these reaches. About 3 m or more of channel incision was recorded at half of the investigated gauging stations from these reaches and in many stations the incision was especially rapid in the second half of the century. In the second half of the century channel incision became also apparent in the upper course of Carpathian tributaries to the Vistula and in their mountain tributaries. The hydrometric data indicate 0.5-2.8 m of channel incision, but at the majority of the gauging stations in these reaches the amount of incision was relatively low,

ranging from 0.5 to 1.0 m.

Variability in the hydraulic importance of channel incision with increasing river size was analysed by comparing changes in the frequency of valley floor inundation at gauging stations located along the 7th-order Dunajec River. Despite a lower nominal amount of channel incision in the upper river course, here incision has increased channel conveyance and reduced the frequency of valley-floor inundation considerably more than in the lower course. Following channel incision by 0.37 m at the Kiry gauging station located in the upper river course, the stage which in 1962 was associated with a flow of 1.5-year recurrence interval in 1995 could be attained by the discharge 4.1 times greater, with a 16.3-year return period. In turn, the level inundated previously by a 5-year flood in 1995 could only be submerged by the discharge 2.8 times greater, with a 140-year recurrence interval. In contrast, at the Żabno station located in the lower course with about 200 times greater catchment size, the absolute amount of channel incision was greatest among the stations considered (2.8 m) but the effect of incision on channel conveyance and the frequency of valley-floor inundation was least significant. The stage, which in 1925 was associated with a 1.5-year flow, in 1998 could be reached by the discharge 1.5 times greater, with a 2.1-year return period. The level inundated at the beginning of the analysed period by a 5-year flood, at its end would be attained by the discharge only 5% greater, which recurs every 5.5 years, on average.

4 LATERAL CHANNEL MOBILITY AND HYDRAULIC EFFECTS OF INCISION

Not only river size but also lateral stability/mobility of the channel accompanying river incision may affect its impact on the hydraulics of flood flows. Considerable differences in the degree of lateral channel stability during the 20th century occurred between low-energy rivers draining the eastern part of the Polish Carpathians and high-energy rivers from the western part (Wyżga, 2001). Low-energy rivers from the eastern part of the Polish Carpathians remained laterally stable during channel incision. This has resulted in substantial lowering of stages for low flood discharges and markedly smaller one for high-magnitude floods, whereas velocity of the flows conveyed over the highly elevated floodplains has decreased considerably. In high-energy rivers from the western part of the Polish Carpathians, alternation of incision of the regulated channel and lateral channel migration has led to the formation of incised meander belts, with substantially lowered stages for all flood discharges and increased velocity of the flows conveyed over the newly-formed, low-lying floodplains.

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