ROLE OF COARSE WOODY DEBRIS (CWD) IN FORMATION OF BOTTOM OF MEANDERING RIVER CHANNEL (A CASE STUDY OF THE MAŁA PANEW – OPOLE PLAIN)

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Ireneusz Malik: Role of Coarse Woody Debris (CWD) in formation of bottom of meandering river channel (a case study of the Mała Panew – Opole Plain). Geomorphologia Slovaca et Bohemica, 7, 2007, 2, 9 Figs., 37 Refs.

The role of Coarse Woody Debris (CWD) in formation of sandy channel bottom of meandering river flowing through the Silesian Lowland was investigated. In result of lateral erosion trees covering terrace levels, undercut by river, are overturned into the channel, where they occur as CWD. In dependence on their amount, position in relation to the channel axe, location and intensity of redeposition they can capture alluvia and cause increased accumulation and erosion at the channel bottom. Large depositional and erosional forms most often occur at the channel in result of influence of CWD accumulation or individual logs, which are located in the channel transversally in relation to its axis. To main deposition forms occurring in the Mała Panew river channel and caused by CWD belong sand shadows and outwashes. Sand shadows originate behind CWD in result of flow separation in hydraulic shadow of the barrier, whereas the outwashes are located behind and partially before the CWD or individual log, they originate in result of increased deposition of material under the convex channel bank. CWD also generate small erosional forms, to which belong as follows: reverse depressions, streamlined depressions and overflow kettles. Reverse depressions are basin-like erosional forms, originating before CWD in result of water flowing under it and forming here spiral whirls. Streamlined depressions are longitudinal erosional forms located at the border of logs originating in result of bottom erosion resulting from flowing mostly round log accumulation. Overflow kettles are oval depressions located behind CWD, originating in result of both water overflowing above the barrier and bottom erosion caused by the influence of spiral whirls.

Key words: Coarse Woody Debris, riverbed morphology, channel sinuosity, riverbed erosion forms, riverbed accumulation forms, southern Poland

1 INTRODUCTION

During the Holocene warming, river valleys in large areas of the former periglacial zone became forested. Vegetation began to have intensive impact on the shaping of the river channel pattern. Due to the fact that man's pressure on the environment was particularly strong during the last two centuries, valleys with natural riparian forests typical for temperate zones have now become rare. Therefore many palaeogeographical reconstructions concerning the formation of alluvial sediments as well as the reasons for changes in the course of river channels do not sufficiently account for the past role of vegetation. The impact of coarse woody debris (CWD) on the functioning of fluvial systems in mountain environments has been well researched. It manifests itself in particular in changes in river morphology, hydraulics and high water flow; CWD also influences erosion, transport and sedimentation processes (WYŻGA et al. 2003).

The Mała Panew, which flows through over 20 kilometres of compact forest complex, is one of the few areas in Central Europe where the impact of vegetation on river channel formation can be studied. One of the ways in which vegetation influences the formation of the river channel pattern is the impact of riparian forests growing directly on river banks. As a result of lateral migration, the trees forming the riparian forest fall into the channel. The fallen trees lie in the channel as CWD and modify erosion, transport and sedimentation processes. The term "CWD" as used in this paper refers to parts of dead trees at least 1 m long and with a diameter (measured halfway along their length) of at least 10 cm (VAN SICKLE and GREGORY 1990).

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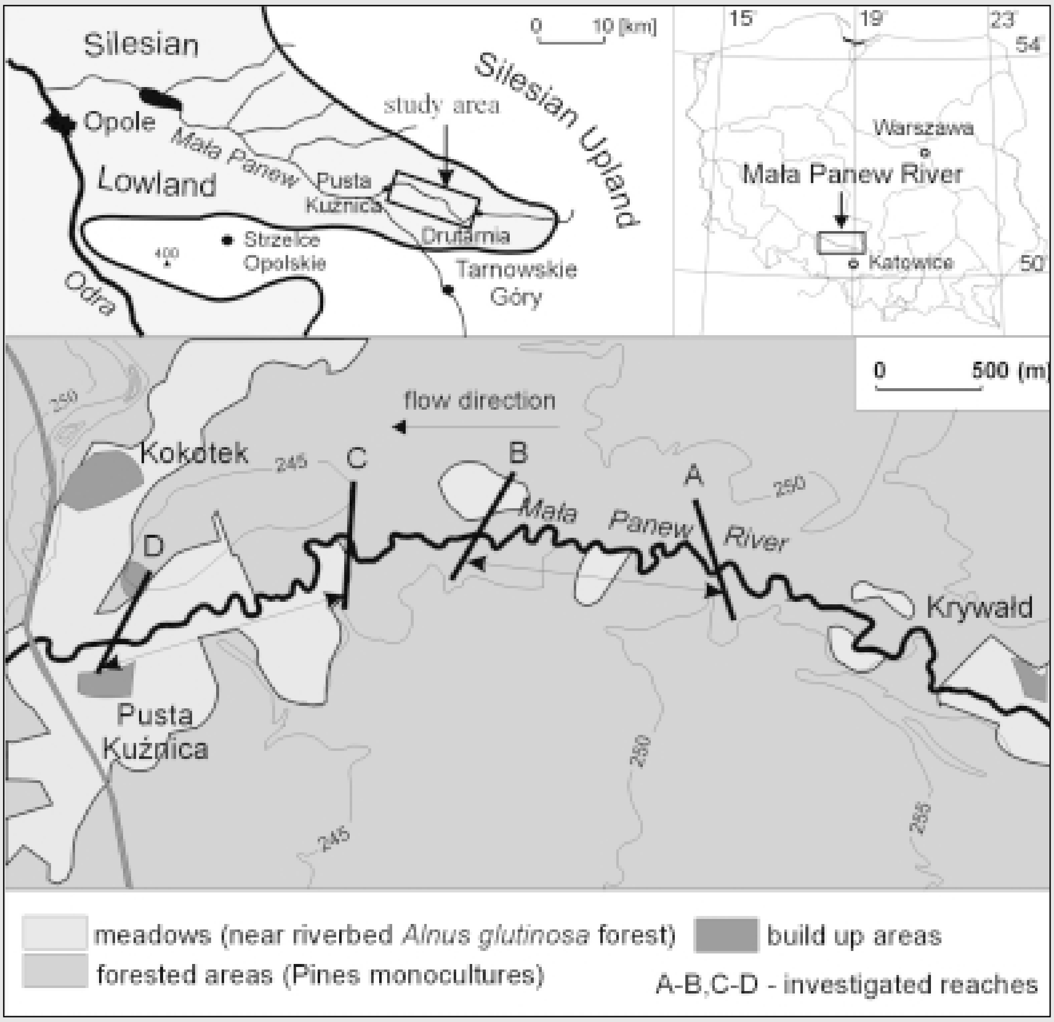


Fig. 1 Location of study area

The term "CWD" is defined in specialist literature as:

CWD (Coarse Woody Debris):
– fallen and standing dead tree parts with a diameter exceeding 15 cm (SOLLINS 1982),
– fallen dead trees and parts thereof with a diameter exceeding 5 cm (HARMON et al. 1986),
– fallen and standing dead trees and parts thereof with a diameter exceeding 10 cm (Spies et al. 1988),
– fallen and standing dead trees and parts thereof with a diameter exceeding 7.5 cm (QUESNEL 1994),

LOD (Large Organic Debris):
– fallen trees and parts thereof with a diameter exceeding 10 cm (BISSON et al. 1987),

LWD (Large Woody Debris):
– fallen trees and parts thereof with a diameter exceeding 10 cm and length exceeding 1 m (VAN SICKLE and GREGORY 1990).

The research regarding CWD in meandering river channels pertains to four basic issues (GURNELL and SWEET 1998).

I. Changes in channel hydraulics caused by CWD (MacDONALD et al. 1982, EHRMAN and LAMBERTI 1992). The research conducted has demonstrated that a relationship obtains between the impact of high water episodes and the number of CWD pieces and trees within the channel. Depending on the number of CWD pieces within the channel, differences also emerge regarding the direction of the river current during high water episodes (HARVEY and BENCALA 1993).

II. The determination of the impact of CWD and trees on the erosion, transport and sedimentation of mineral and organic material filling the riverbed (KELLER and SWANSON 1979, LISLE and KELSEY 1982).

III. The impact of CWD and trees on the formation of the channel pattern of sand-bed rivers. It manifests itself in the differentiation of river channel width (KELLER and SWANSON 1979, HOGAN 1985), changes in the size and pattern of pool formations and sand bars (RACHOCKI 1978, ANDRUS et al. 1988, ROBISON and BESCHTA 1990) and in river channel stabilisation (BILBY 1984).

IV. Increase in biodiversity and bioproductivity (ANDERSON and SEDELL 1979).

2 Study area

The valley of the Mała Panew runs along an east-west axis through the Opole Plain which forms part of the Silesian Lowland; its middle reach is situated within the Silesian Highland (KONDRACKI 1998); (**Fig. 1**). The study area included forested areas of the Mała Panew valley. Detailed research was conducted along two two-kilometre reaches of the river channel (A–B and C–D) between Krywałd and Pusta Kuźnica (**Fig. 1**). This area is situated in the place where in the course of its subsequent subsidence the Mała Panew reaches the Silesian Lowland (KLIMEK 1972). The bottom of the Mała Panew valley is filled with glacial and fluvioglacial sediments from the Middle Polish Glaciation (WŁODEK 1976). Due to the nature of these sediments, the alluvia formed as a result of their redeposition are largely sands of varying grain size. The mean grainsize of the channel facies (channel and meandering bar level sediments) within the reaches examined ranges from 1.8 to 2.8 phi, while for overbank sediments (floodplain) it ranges from 2.3 to 3.3 phi. Sand grains forming the floodplain are finer (2.73 phi on average) than channel sediments (2.03 phi on average). The standard deviation of channel sediments (0.63 phi on average) is better than that of floodplain sediments (0.98 phi on average); (MALIK 2004).

The analysis of topographic maps and field research enabled us to identify terrace levels with diverse morphologies within the valley. Within the reach examined, a Pleistocene terrace around 2–3 km wide is present on the right bank side of the Mała Panew valley (PRZYBYLSKI 1994). Below it, a few isolated mounds composed of sands of varying grain sizes (3–4 m) and two Holocene terraces are situated (2–3 m; 0.5–2 m; floodplain).

The present Mała Panew channel is a meandering one. There are numerous bends with varying diameters in the river—such features are typical for areas with forested banks. The channel cuts around 0.5–2 m deep into the floodplain. The geometric parameters of the Mała Panew channel are primarily determined by the hydrological regime. Annual rainfall within the basin ranges from 500 to 750 cm/sq. m (PUNZET 1957), the river is supplied by runoff and melting snow (DYNOWSKA 1971). The gradient of the Mała Panew valley within the reach examined amounts to 1.2 ‰. The width of the river in forested areas does not exceed 15 m while its depth at average water stage reaches up to 2 m. As evidenced by the data collected by the hydrological station at Krupski Młyn, annual water stage amplitudes are significant and sometimes amount to well over 300 cm. Within the last ten years, high water episodes related to spring and summer rains have prevailed. Earlier, spring thaw floods prevailed.

The study area is potentially situated within the area where subcontinental mixed pine and oak forest (*Pino-Quercetum*) prevails (CELIŃSKI, MEDWECKA-KORNAŚ and WIKA 1978). The natural environment of the Mała Panew Subsidence has been significantly altered by man's pressure on the environment. As a result, vegetation differs significantly from the basic potential vegetation communities which should grow within the study area. The forests growing within the Mała Panew Subsidence are mainly forest communities. The most popular and best preserved complexes include:
- *Leucobryo-Pinetum* (mesic sub-Atlantic pine forest);
- *Calamagrostio villosae-Pinetum* (marshy coniferous forest);
- *Molinio-Pinetum* (moist pine forest).

Areas of ash-alder carr (*Circaeo Alnetum*) are visible on river banks as well as near ditches and streams. Areas of willow-poplar forest (*Salici Populetum*), alder carr (*Ribo nigri-Alnetum*), and elm-alder stands (*Astrantio-Fraxinetum*) may also be found in the valley (CABAŁA 1990).

In the study area, directly above the erosion undercuts of the concave river bank (maximum 2 metres), alder (42 %), pine (35 %), willow (20.5 %) and spruce (2 %) dominate. Hornbeam, lime and birch occur here sporadically but due to the very low number of individuals of those tree species they have not been included in the calculations.

3 Research objective and methods

The objective of this paper is to determine the role of CWD in the development of the riverbed of meandering rivers. The study was carried on from 2000 to 2002. During the first stage of field research, an inventory of CWD within the channel was carried out, consisting in the determination of the number, position and orientation of CWD pieces relative to the channel axis using angle division (**Fig. 2a**). In order to determine the orientation of CWD relative to the river channel axis, during the first stage CWD pieces were visually fitted to the angle scale (they have been marked in black in **Fig. 2a**). After a piece of CWD was fitted to a specific circular sector (marked in grey in **Fig. 2a**), its approximate position was determined. Redeposition intensity which influences the position of CWD within the channel was also examined. The paper suggests several methods of distinguishing CWD lying in situ in sediments or within the river channel from redeposited and reoriented CWD. It may be assumed that all CWD pieces whose root systems and trunks lie in the channel and their tops lie on the bank are in the in situ position. Redeposited CWD may be recognised by the lack of bark and sapwood which are stripped during river transport (KRĄPIEC 1992). Soft sapwood constitutes the outer part of the tree and consists of tree rings which developed during recent vegetation periods. When identifying redeposited CWD, the analysis of the orientation of CWD relative to the channel axis may also be useful. Trees lying in situ are

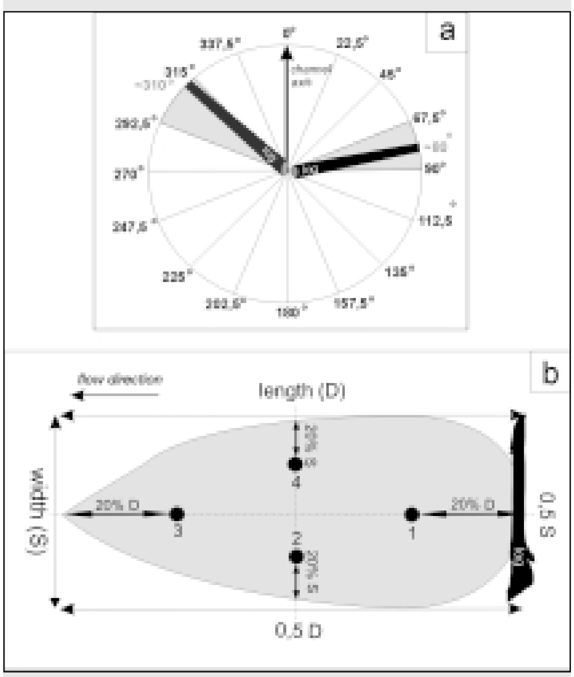


Fig. 2 Methods of determine position of CWD in relation to the channel axe (**a**) – sampling sites (1-4) methods (**b**)

usually positioned transverse to the channel axis while redeposited and reoriented trees lie along the river channel axis.

In order to determine the impact of CWD on the formation of the Mała Panew riverbed, the mechanism of development of erosion and accumulation forms within the riverbed was examined. To this purpose, 6 m long and 2 m high graduated poles were used to probe forms on the riverbed. The impact of each piece of CWD on riverbed morphology was determined. Typical cases of CWD impact on the morphology of the river channel were identified and grouped together. For selected sites, riverbed configuration maps were drawn up, which demonstrated the presence of both accumulation and erosion forms within the Mała Panew river channel. The channel forms analysed were observed at water stages similar to multiannual averages.

In order to examine the functioning of accumulation forms generated by CWD more thoroughly, mean grainsize analysis was conducted at selected sites using the sieve method. The granulometric structures of four large (over 2 m long) and four small sand shadows as well as of four river channel bars were analysed. Using formulas developed by R. L. FOLK and W. C. WARD, the most important grain parameters for the sediments constituting the forms generated by CWD (i.e. mean grainsize Mz and standard deviation W) were calculated (RACINOWSKI and SZCZYPEK 1985). The methods of sampling forms generated by CWD are shown in **Fig. 2b**. The sampling sequence was determined in a clockwise manner and the river current was the axis determining sampling points. Depending on the thickness of sediments constituting river channel deposition forms, from two up to ten samples were collected from each excavation unit at 10 cm intervals. The results were compared to grain parameters analysis results for river channel deposits forming meandering bar levels and sediments deposited on the Mała Panew floodplain. The objective of grain parameters comparisons was to determine the manner in which the forms generated by trees and CWD in the river channel developed and functioned. Channel forms generated by CWD which were built up during subsequent high water episodes and as a result were present within the channel for a relatively long time as well as small and short-lived forms consisting of channel facies sediments were identified.

4 Results and discussion

4.1 Number, position and orientation of CWD pieces lying in the channel

There are a manyfactors that influence the number of CWD pieces lying in river channels; the most important are the shape of the valley, the width of the channel, the type of alluvial material filling the valley floor, the gradient of the river, the species of trees growing on river banks and the manner in which CWD is supplied to the river channel (MALIK 2004).

The examined reaches of the Mała Panew channel exhibit significant differences with regard to the height of erosion undercuts and the composition of trees growing on river banks. The remaining factors under analysis that influence the pattern of CWD within the channel—the type of alluvial material filling the valley, the width of the channel and the gradient—are very similar in the reaches examined. The factors determining the number and layout of CWD pieces within the Mała Panew channel are listed in table.

The total number of CWD pieces within the reaches of the Mała Panew river channel examined amounts to 1123. The overwhelming number of CWD pieces (839 – 73.1 %) lie in the A–B reach. 305 CWD pieces (26.8 %) were recorded in the C–D reach. In the A–B reach, higher terrace levels are overgrown with pine dominated forests. In the C–D reach, riparian forest trees (overwhelmingly dominated by black alder) are present. The much larger number of CWD pieces within the A–B reach is to a certain extent the result of differences in the structure of root systems of the trees growing on river banks. Pines, which dominate in the A–B reach, have tap root systems—they do not protect the bank from erosion and easily fallen into the Mała Panew channel. Alders and willows, which grow on river banks in the C–D reach, have fibrous root systems, which reinforce river banks and limit erosion at the same time. The large disproportion in the numbers of CWD pieces in examined reaches is also influenced by the difference in the height of lateral erosion undercuts. In the A–B reach, the river cuts below the root

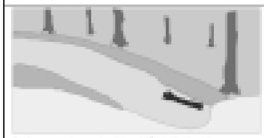
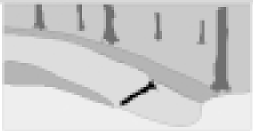
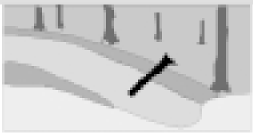
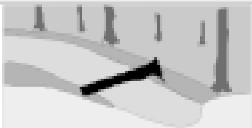
	Reach AB	Reach CD
 1. Less than half of CWD in the riverbed	563 (67,9%)	217 (71,1%)
 2. More than half of CWD in the riverbed	139 (16,8%)	45 (14,8%)
 3. Bottom of the CWD on the bank and the end of the CWD on the riverbed	113 (13,6%)	28 (9,2%)
 4. Ends of CWD on the opposite river banks	14 (1,7%)	15 (4,9%)

Fig. 3 Position of logs in the Mała Panew riverbed

systems of the trees overgrowing its banks and moreover, higher terrace levels are usually reached by the lateral migration of the channel. Therefore at high water stages, when the lateral erosion is the strongest, the river easily erodes the sandy material constituting its banks. Progressing lateral erosion regularly undercuts the trees growing on banks (MALIK 2002 and 2006). This is accompanied by an increased supply of CWD into the channel.

The pines and spruces that dominate in the A–B reach are built of much harder wood than willows and alders. Soft CWD which gets into the river channel after riparian forest trees have fallen rapidly decomposes. This is one of the reasons why the number of CWD pieces is much lower in the C–D reach where alders and willows dominate. The disproportion in the numbers of CWD pieces in examined reaches may also be influenced by the proximity of dwellings to the C–D reach. Alder wood makes for good fuel—perhaps after alders fall into the channel, they are dragged out and burned on hearths.

The Mała Panew channel is wide enough so that the tops of most fallen trees which fall into the river channel do not reach the opposite bank. There are some cases in the A–B reach where pines and spruces which have grown for several decades are much taller than the width of the river channel. However, the considerable gradient of the slopes developed as a result of older terrace levels being undercut often causes a situation where the root system and trunk of the felled tree lie on one bank and the top within the channel. Four basic cases may be distinguished with regard to the position of CWD within the Mała Panew channel (**Fig. 3**). The negligible number of CWD pieces forming bridges suggests that most fallen trees get directly into the channel.

The layout of CWD within the Mała Panew channel is also influenced by the intensity of its redeposition and reorientation. This process is also important from the point of view of the possibility of dating the sediments in which CWD lies and the interpretation of processes which caused the deposition of CWD. **Fig. 4** shows the orientation of CWD relative to the Mała Panew channel axis, which makes it possible to identify the CWD pieces which probably lie in situ in the channel. Around 210 CWD pieces lie transverse to the channel axis and 320 are parallel to the river current. The criteria adopted make it possible to identify the CWD which certainly lies in situ in the channel—this group includes CWD pieces which form bridges, those whose one end lies in the channel and the other on a bank as well as CWD pieces with bark on them which lie transverse to the channel axis (228 CWD pieces - 20 % of the total number). CWD pieces which probably lie in situ form another group, which includes the remaining pieces lying transverse to the flow direction (164 CWD pieces –15 %). The remaining CWD pieces were probably redeposited or reoriented (731 CWD pieces – 65 %).

4.2 Types and origin of deposition riverbed forms generated by CWD

Two types of deposition forms generated by CWD are present in the Mała Panew riverbed; these are sand shadows and river channel bars. The sand shadows which occur within the river channel are of different

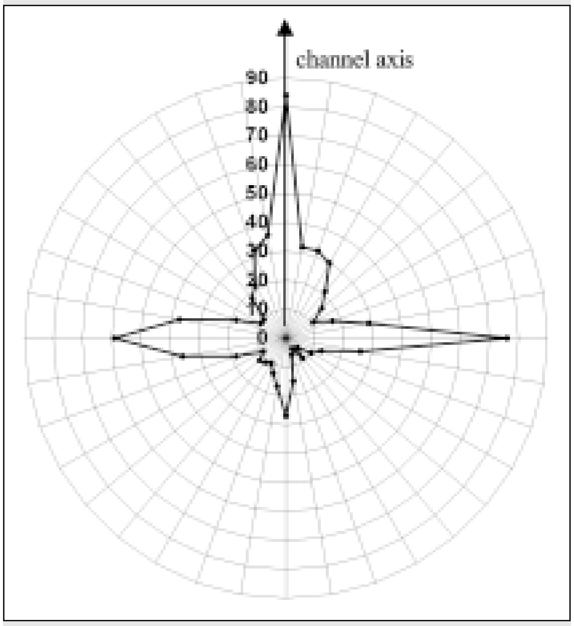


Fig. 4 CWD position in relation to the channel axe in investigated reaches

sizes; their size largely depends on the length and width of CWD pieces, their location within the channel and orientation relative to the channel axis. They are formed in the hydraulic shadow of single CWD pieces or CWD groups due to the separation of flow and the precipitation of material in the swirl zone. Sand shadows generated by CWD are of oblong shape, they are usually the widest at one quarter of their length. The side facing the current has a semicircular shape while the side away from the current is pointed; its direction may be skewed parallel to the main flow direction. The largest such forms occur near the convex bank. They are sometimes more than ten metres long (**Fig. 5**). They form due to the impact of CWD groups or large CWD pieces lying transverse to the channel axis. They consist of overbank sediments (particularly in their uppermost part) and are overgrown with herbaceous plants, which facilitates their build-up during high water episodes. Thus such forms may be present within the channel for a relatively long time. The average diameter of mean grainsize forming shadows ranges from 2 to 2.52 phi; the average calculated for four large shadows was 2.33 phi. The standard deviation of sediments forming shadows ranges from 0.58 to 0.95 phi; the average value was 0.75 phi.

Small sand shadows consist of channel facies sediments, which means that they are not built up during high water episodes and are often washed out due to their relatively small size. The mean grainsize forming shadows ranges from 1.36 to 2.3 phi; the average calculated for four small shadows was 1.66 phi. The standard deviation of sediments forming shadows ranges from 0.44 to 0.76 phi; the average value was 0.65 phi.

River channel bars are accumulation forms which build up before an obstruction and partly behind it. They are usually situated directly next to the convex bank (**Fig. 6**). These are small forms (up to 2 metres long). They form due to the impact of CWD situated near to the convex bank, which stimulates the accumulation of material, accelerating the build-up of the meandering bar level. Such forms are relatively short-lived, which is evidenced by their small size and granulometric structure similar to that of channel facies sediments. The mean grainsize forming bars ranges from 1.28 to 1.96 phi; the average calculated for four bars was 1.54 phi. The standard deviation of sediments forming channel bars shadows ranges from 0.46 to 0.83 phi; the average value was 0.61 phi.

4.3. *Types and origin of erosion riverbed forms generated by CWD*

Erosion forms appear due to the impact of CWD in the Mała Panew channel. Backwater pools, crescentic pools and plunge pools have been identified during research.

Backwater pools are erosion forms which are very numerous in the Mała Panew channel. In the view of the author, they represent structures known as "crescentic scours" in the literature. Crescentic scours form due to intensified erosion caused by disturbances in the pattern of current lines directly adjacent to objects present in the riverbed (GRADZIŃSKI et al. 1986). The formation of erosion pools due to the impact of CWD is discussed at length in the literature (GURNELL and SWEET 1998). C. A. DOLLOFF (1994) has made an attempt to classify such pools depending on the position of CWD pieces in the channel. He divides erosion pool formations generated by CWD into dam pools, plunge pools and backwater scours. The backwater pools described by the author are arcs situated transverse to the channel axis. The arms of the arc are bent accordingly to the flow direction. Erosion forms of this kind are usually found before long CWD pieces positioned transverse to the channel axis (**Fig. 7**). Backwater pools form due to the impact of spiral eddies before the obstruction. The semicircular shape of the current-facing side of CWD pieces divides the current into two parts. One arm penetrates below the CWD and when it approaches the riverbed, the water flows back, causing erosion before the obstruction. The second arm of the current flows above the obstruction. Where a CWD piece does not touch the riverbed, the water flows beneath and a pool is also formed below.

Fig. 5 Big sand shadows in Mała Panew riverbed

Fug. 6 Outwash in Mała Panew riverbed

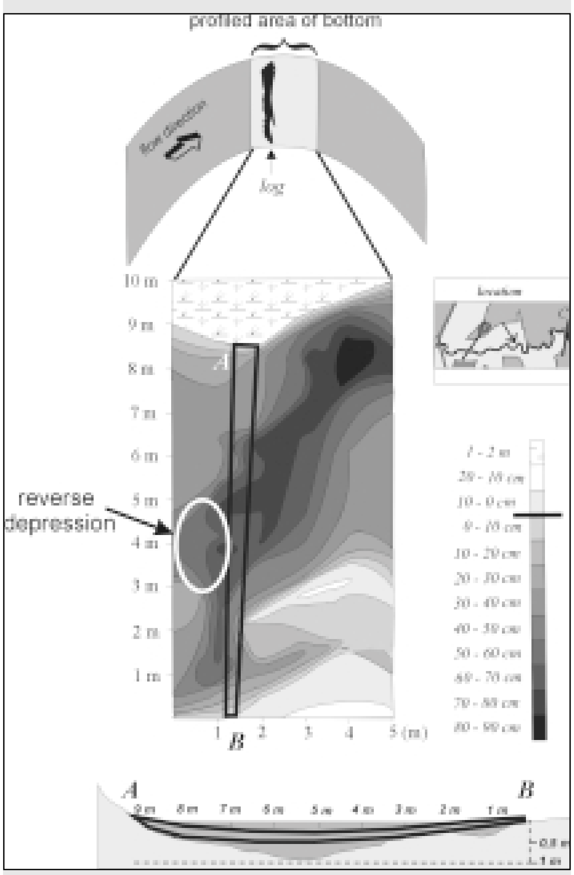


Fig. 7 Reverse depression in the Mała Panew riverbed

Crescentic pools are erosion forms which can be found at the edges of obstructions. They usually accompany large CWD groups and manifest themselves as clearly visible, oblong overdeepenings which may be several metres long. They form due to the erosion of the riverbed caused by the water flowing around obstructions (**Fig. 8**). Sometimes crescentic pools also form around the sides of small CWD pieces situated parallel to the current. Such forms are much smaller.

Plunge pools situated behind obstructions are another erosion form generated by CWD recorded within the Mała Panew riverbed. They are oval erosion forms caused by water flowing over obstructions, similar to potholes generated by CWD in mountainous areas (KACZKA 1999); (**Fig. 8**). Plunge pools only form when the water stage is sufficiently high—the water flows above the obstruction, forming a pool in its shadow.

4.4. Number and situation of channel forms generated by CWD

The 891 sand shadows are present in the Mała Panew channel, which amounts to 39% of all forms found there; 73 % of that number are small sand shadows. During the research, as many as 752 (33 %) backwater pools were found; also crescentic pools are quite numerous in the Mała Panew riverbed—431 forms were recorded (19 %). River channel bars and plunge pools are less numerous in the river channel —129 (6 %) and 66 (3 %) were found, respectively (**Fig. 9**).

The numbers of forms generated by CWD differ in the reaches of the Mała Panew river channel examined (**Fig. 9**). A much higher number of erosion and accumulation riverbed forms can be found in the A–B reach; this is understandable, taking into account the higher number of CWD pieces in this reach. The forms here are larger, just as the CWD pieces which initiate their formation.

5 Conclusions

CWD have fallen into the river channel mainly in reaches where the river cuts deep into the alluvia. Even during significant high water episodes, the river stays within the channel there. Significant erosion takes place at such times, particularly within concave banks. Erosion fells large pines, elms and oaks which grow on higher terraces. CWD pieces which lie in the stream due to such trees being undercut are long-lived and initiate the development of large riverbed forms.

In reaches where banks are lower, significant high water episodes cause the water to reach the floodplain

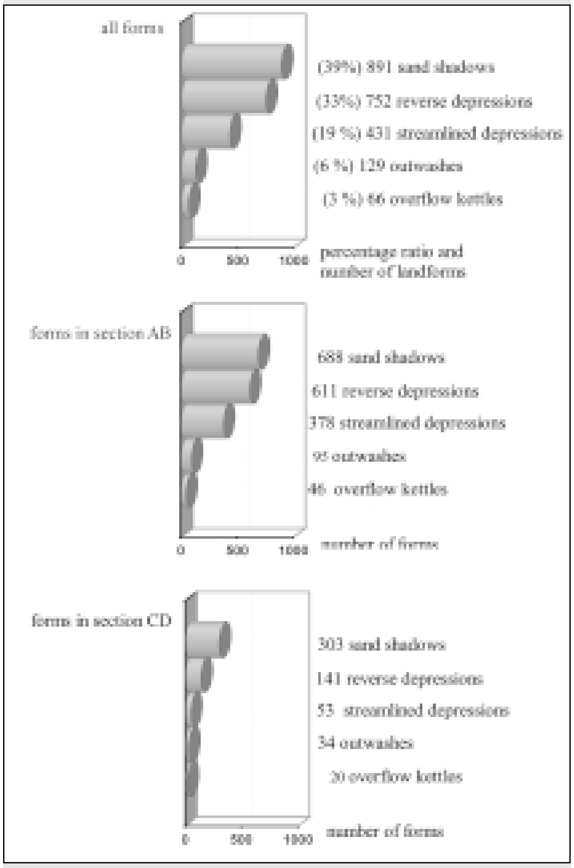


Fig. 9 Quantitative share and percentage ratio of channel forms originated at the participation of CWD in the investigated sections of the Mała Panew channel

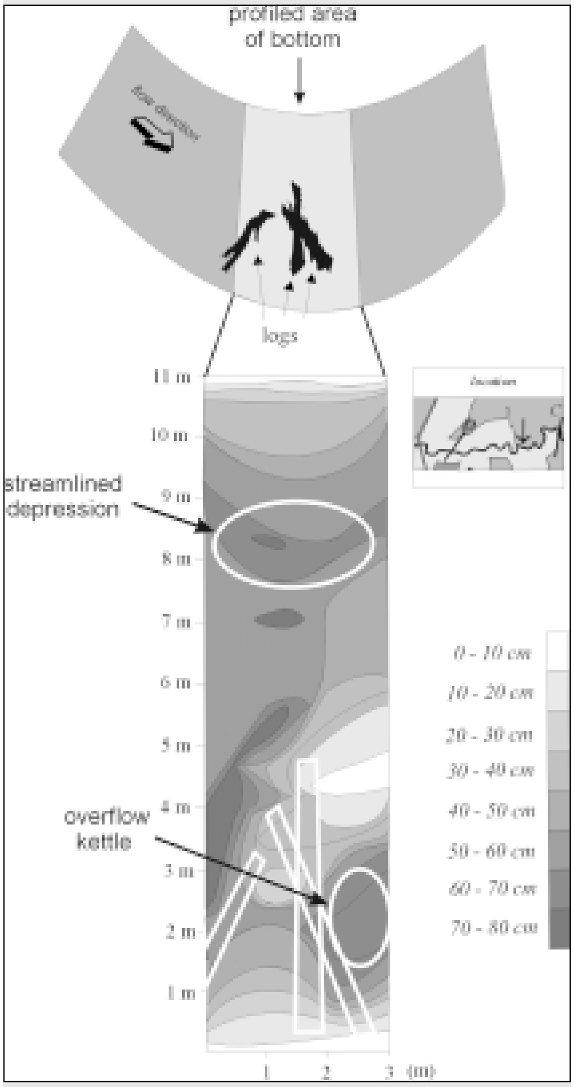


Fig. 8 Streamlined depression and overflow kettle in the Mała Panew riverbed

and the banks are only eroded to a small extent. The riparian forest here is composed of alders and willows, which are flexible trees and do not supply a large number of CWD pieces into the river channel. Moreover, alders and willows consolidate banks with their root systems and thus protect them from erosion. This prevents the rapid lateral migration of the river channel and therefore the number of CWD pieces and associated river channel forms is relatively limited in reaches with low banks.

Deposition or erosion forms accompany almost all CWD pieces lying in the river channel. Sand shadows and river channel bars are usually much larger than backwater pools, crescentic pools and plunge pools. This means that CWD generally contributes to an increase in river channel deposition. CWD lying in the channels of small meandering rivers (as opposed to mountain rivers) does not obstruct the entire river channel. Therefore its role in modelling the longitudinal profile is limited. Water flows around large CWD pieces or groups thereof lying near the concave bank. The river then undercuts the convex bank, which is usually being built up. At the same time material is deposited near the concave bank, i.e. in a zone where erosion should prevail. This process causes frequent changes in the direction in which bends develop and a river which flows through homogeneous alluvia becomes irregularly winding due to the impact of CWD and the forms generated by its presence. With regard to the riverbed, the natural meandering river channel pattern of basins situated below the edges of the concave bank and meandering bar levels built up near the convex bank becomes obscured.

Meandering rivers, as opposed to rivers flowing through mountain areas, typically exhibit erosion zones before or beside obstructions and deposition zones are usually found below CWD. In mountain rivers in turn, erosion occurs below CWD obstructions and deposition above them (NAKAMURA and SWANSON 1993, KACZKA 2003).

The configuration of a meandering riverbed changes together with variations in the speed of water flow. It should be supposed that erosion processes occur within the river channel when the high water stage reaches its culmination. CWD as well the material building the forms generated by them may be transported. When the flood-wave subsides, material accumulation is initiated—CWD is deposited and new river channel forms begin to develop nearby. In general, river channel forms in meandering rivers are more long-lived than CWD-generated forms in mountain rivers. This is evidenced by the relatively large number of CWD pieces lying in situ in the Mała Panew river channel. CWD in mountain rivers is redeposited more frequently.

Research conducted within meandering river channels has shown that such rivers bury CWD within the convex bank during the course of their lateral movement. When conditions are favourable, such CWD is fossilised within meandering bar levels. Together with CWD, fossil channel forms generated by CWD pieces should be present in sediments.

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