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# GEOMORPHIC STRUCTURE AND LAND COVER OF EXTENSIVELY MANAGED FLOODPLAINS OF THE NIDA RIVER

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**Abstract:** The aim of this paper is to define relations between the morphology of a river valley floor and its land cover, and to assess the degree in which a natural river allows management practices within the valley floor. A 30-km fragment of the lower Nida River valley floor was divided into 60 equal sections and 60 corresponding transects were marked across the valley floor. Basic geomorphic parameters were measured for each section, as well as the area covered by each type of land use. Relationships between land cover and geomorphic features were tested using stepwise regression. Meadows were the prevailing type of land cover; they covered over 70 percent of the floodplain; their area was positively correlated mainly with the width of the valley floor and, to a lesser degree, with the width of the meander belt and the depth of low-water channel. The area of arable land was positively correlated with the number of isohypses crossing the considered section of the valley floor, to a lesser degree with the width of floodplain, and negatively correlated with the width of the meander belt. While the riverine forest area was positively correlated with the channel gradient, correlations with the width of the avulsion belt and the difference in elevation between channel and floodplain edge were negative. The two latter parameters were also negatively correlated with the area of willow shrubs. Small woodlots were not related to any trait of the valley, except for the river depth. The length of unsurfaced country roads was positively correlated to the widths of the valley floor and meander belt. Human settlements within the valley were present only in the lower part of the watercourse, of an accumulative channel character. The length of ditches was not correlated with any morphologic trait of the river valley.

**Key words:** floodplain, meadows, extensive agriculture, flood, riverine forest, channel, Nida River

## INTRODUCTION

Channels and floodplains are ultimately shaped by a sequence of flows and sediment loads carried by rivers. According to the flood pulse concept (Junk et al. 1989), a spectrum of geomorphologic and hydrological conditions produces flood events, which are short and unpredictable in the headwater stream and in streams substantially modified by human activities. In larger and/or natural rivers flood events are longer and more predictable. The result is that both the structure of the riverbed and biota associated with a river reflect the characteristics of its flood regime.

Riparian corridors are unique in experiencing intense geomorphic disturbances on a regular and consistent basis. Lateral channel migration is the main process shifting one landform type to another, e.g. eroding material from a floodplain and depositing it on a bar. The wide variety of habitats found in riparian areas is a direct result of these destructive and constructive disturbances (Pollock 1998).

The two processes described above imply that both landscape structure and man activities in a natural or semi-natural river valley should be influenced by flood pulses and lateral migration of the river.

During the last 200 years most rivers in developed countries were transformed into more or less artificial systems in order to improve flood conveyance and gain agricultural lands (Allan 1995). This was related to the elimination of two basic activities of natural rivers: floodplain inundation and the lateral migration of channels. The changes resulted in disastrous impoverishment of riverine biocenoses and the intensification of human activity in river valleys. This factor, never present there before, irreversibly changed the structure of valleys.

Nowadays, due to releasing economical reasons for land reclamation and increased ecological awareness, there is a growing interest in rich, developed societies to restore the natural value of rivers. These concepts gained wide acceptance in aquatic ecology at the end of the 20th century (Frissell and Ralph 1998). However, restoration practice is sometimes difficult due to poor knowledge of the functioning of natural or semi-natural riverine ecosystems; such efforts, therefore, do not result in restoring natural processes but in imitating them by building artificial structures (e.g. RSPB et al. 1995).

Restoration is an act of relaxing human constraints on the development of natural, spontaneous processes (Frissell and Bayles 1996). A restored ecosystem does not necessarily return to a pristine state but it can experience the range of processes that shape diverse habitats thus enriching their biodiversity. Restoration must be an integrated element of watershed management. This means that not only should restoration take into account the welfare of wildlife but it also must consider the constraints of local demography, economy, resource consumption, cultural values etc., all of which require sustainable development. In order to develop sustainable management plans for rivers, it is necessary to have good examples of the sustainable use of riverine habitats that preserve natural processes and allow human activities. Examples of such management can be found among extensively used river valleys of Poland.

The aim of this paper is to answer two questions:

1. What are the direct relations between a given form of river valley and land cover types?
2. How does a river, while saving its natural character, allow man to perform his activities in the valley floor?

Describing such relationships will enable the correct and concert planning of economic and nature conservation activities, on the basis of easily identifiable geomorphological traits, readable in basic maps.

## STUDY AREA AND METHODS

The study was carried out in 1999 and 2000 in the Nida River valley (50°18'-50°31' N, 20°32'- 20°48' E), southern Poland. The river, 151.2 km in length, is a left side tributary of the Vistula, and drains a watershed of 3,865.4 km² in area (Długość i kilometraż 1978, Podział hydrograficzny Polski 1980, 1983). The study was focused on a 30-km-long, natural section of the river in its lower course, between the towns of Pińczów and Nowy Korczyn. This area was particularly suitable for conducting the study. Although extensively managed since the Middle Ages, the valley was not subjected to river training works and has preserved many of its natural values, representing a typical lowland river in Poland. Due to its natural character, the Nida River Valley was selected as the Natura 2000 site; it is also a core area in the EECONET (Zając et al. 1998).

On the basis of 1:10 000 topographic maps and field reconnaissance, functional river valley boundaries were delimited. Then, a detailed digital map of the study area was prepared using the Arc-Info software; the same software was later used for all analyses. The map contained all layers typical of a topographic map: relief, drainage network, land cover, roads, railways and buildings.

On the map, 60 transects were marked across the valley floor; transects were distributed at a 500 m distance along the valley (fig. 1); 250 m above and 250 m below each transect, two parallel lines were drawn across the valley floor. These lines,

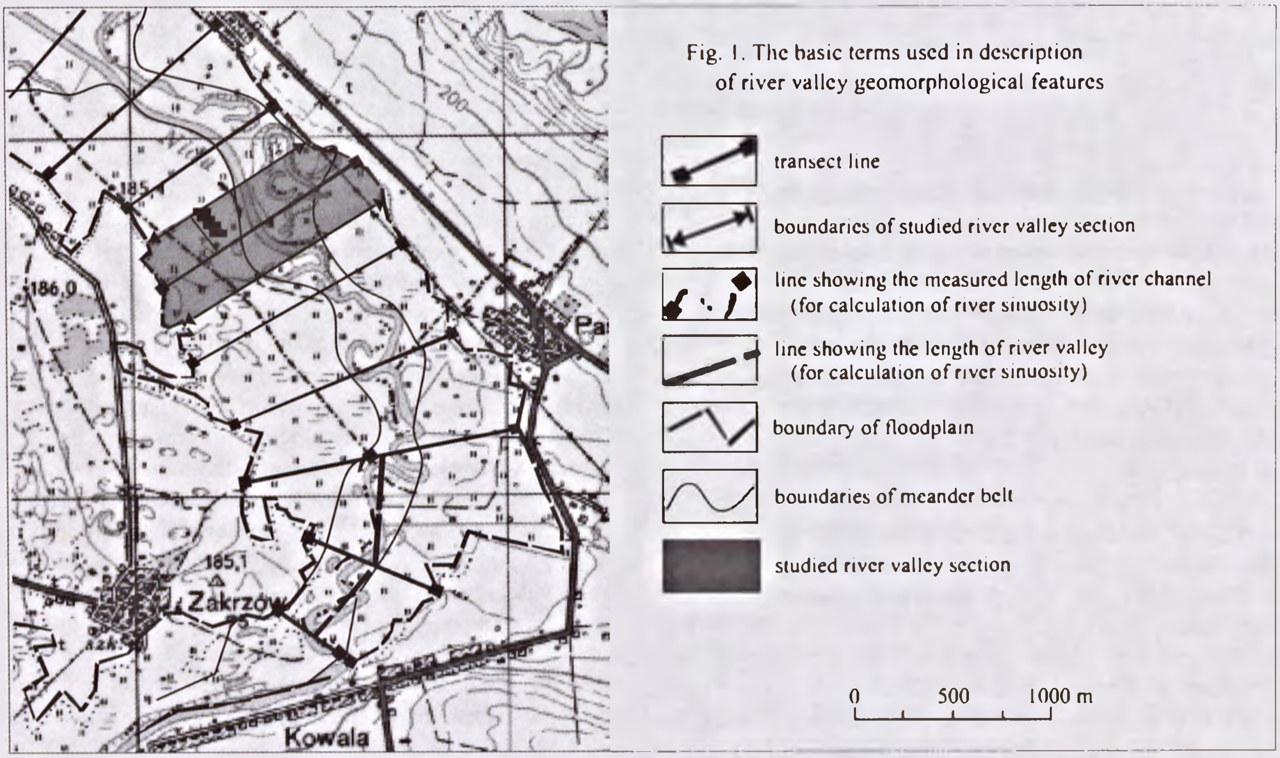
Fig. 1. The basic terms used in description of river valley geomorphological features

together with the distal edges of the valley floor width, divided the study area into 60 sections. Data on the geomorphology of each section was determined for the corresponding transect (assumed to represent the geomorphology of the entire section), whereas data on land cover was collected for the whole section area.

The following set of geomorphological parameters was determined for each section:

1. Distance along the river valley axis ($L$), measured from the first transect.
2. Sinuosity index ($k$), calculated as channel length/valley length ratio.
3. Channel gradient ($J$), calculated as a difference in elevation above sea level between the transects proceeding and following the considered section.
4. Number of isohypses, marked every 1.25 m ($N_p$), intersected by the transect; this parameter reflects the recent history of lateral river activity, because abandoned channels leave a diversified floodplain surface.
5. Width of the floodplain ($W_f$).
6. Width of the meander belt ($W_{men}$), measured as the distance between the most distal meanders (or abandoned meanders) intersected by the transect; this parameter reflects the range of lateral migration of the channel during meandering.
7. Width of the avulsion belt ($W_{avu}$), measured as the distance between the most distal remnants of abandoned river channels intersected by the transect; this parameter reflects the range of channel avulsion.
8. Difference in elevation between the channel and the lowest part of the floodplain ($D$), reflecting recent trends in the vertical position of the river channel.
9. Width of the water table in the channel ($B$); measured during the average water level.
10. Maximum river depth ($H_{max}$).

Parameters 1-8 were measured on the map, while parameters 9-10 were determined in the field.

On the basis of the digital map, the following data on land cover were collected for each river valley section:

- area covered by building plots,
- area covered by meadows,
- area of arable land,
- area of small woods in the agricultural landscape,
- area of riverine forest,
- area of willow shrubs,
- length of asphalt roads,
- length of unsurfaced country roads,
- area covered by the river,
- length of draining facilities.

The area covered by linear features (roads and ditches) was calculated as the total length of the feature within each section, multiplied by three metres for roads, and two metres for ditches.

Table 1. Basic data on habitat cover in the Nida Valley

| | Average [ha] | % | Min [ha] | Max [ha] | S.D. |
|---|---|---|---|---|---|
| Asphalt roads | 0.01 | 0.0 | 0 | 0.2 | 0.03 |
| River | 0.01 | 0.0 | 0 | 0.09 | 0.02 |
| Unsurfaced country roads | 0.2 | 0.2 | 0.07 | 0.5 | 0.11 |
| Ditches | 0.2 | 0.2 | 0 | 0.5 | 0.13 |
| Human settlements | 0.22 | 0.3 | 0 | 3.9 | 0.57 |
| Small woods | 0.4 | 0.5 | 0 | 3.3 | 0.72 |
| Willow shrubs | 0.6 | 0.7 | 0 | 3.8 | 0.87 |
| Forests | 0.7 | 0.8 | 0 | 3.7 | 0.84 |
| Arable land | 9 | 10.8 | 0 | 25.8 | 7.80 |
| Meadows | 72.36 | 86.5 | 17 | 137.09 | 28.60 |

Relations between the land cover features and geomorphic parameters of the valley floor were then studied by means of backward stepwise regression. The variables that showed significant departures from a normal distribution were transformed to approach normality.

## RESULTS

The Nida River floodplain was covered mostly by meadows (tab. 1), accounting for over 3/4 of the valley floor area. Arable lands covered only ca 11 % of the area. The remaining area was covered by very small riverine forests and willow shrubs or small woods; none of these land cover types accounted for more than 1% of the total coverage. The river channel itself and asphalt roads occupied negligible areas, and were therefore excluded from further analysis.

Only a few significant correlations between areas of different types of land cover were found. The area of willow shrubs was negatively correlated with the area of meadows ($r_s = -0.28$, $N = 60$, $p = 0.03$). The length of unsurfaced country roads was positively correlated with the areas of meadows ($r_s = 0.39$, $N = 60$, $p = 0.002$) and arable lands ($r_s = 0.35$, $N = 60$, $p = 0.006$).

Human settlements showed no correlation with any particular trait of the river valley except for the distance along the river valley ($L$) and width of the water table in the channel ($B$; tab. 2, col. 2). The area of meadows showed a very strong positive relationship with the floodplain floor ($W_f$) and, to a lesser degree, with the width of the meandering belt ($W_{men}$) and the maximum river depth ($H_{max}$, tab. 2, col. 3). The arable land area (tab. 2, col. 4) showed a negative correlation with the width of the meander belt, whereas positive relationships were found both for the number of isohypses ($N_p$) and the width of the floodplain floor. The area of small woods in the agricultural landscape showed no correlations with any geomorphic feature of the valley floor (tab. 2, col. 5), except for a negative correlation with the channel depth. The area of riverine forests in turn was related to the channel gradient ($J$), and showed a negative correlation both with the width of the avulsion belt ($W_{avu}$) and with the difference in elevation between the channel and the lowest section of the floodplain ($D$; tab. 2, col. 6). The area of willow shrubs was also related to the latter two variables: $W_{avu}$ and $D$ (tab. 2, col. 7). The length of unsurfaced country roads showed a strong positive relationship with the width of the floodplain and that of the meander belt (tab. 2, col. 8), whereas the length of ditches showed no relation to any geomorphic feature of the valley floor.

## DISCUSSION

Generally, the valley floor of the Nida River was covered by meadows, used for haymaking. One characteristic feature of the whole valley was that there were practically no forests or willow shrubs; each of these vegetation types covered only less than 1 % of the total area. This was undoubtedly the result of the demand for meadows in the vegetation season and for firewood in winter. The Nida Valley is situated far away from coal-basins and transport routes in the area are poorly developed, which has contributed to relatively high coal prices and its restricted availability in this area. Firewood, in turn, is readily available in the winter, when frozen ground makes small patches of wood accessible for logging and transport of the cut trees to farms or sawmills. At this time of year a considerable number of old trees are cut.

Agriculture has never been intensively practised in the Nida River valley. Extensive use of such a large area reflects regular and frequent floods, which occur here almost every year (Łajczak 1997). Such regular flood pulses render any intensive form of agriculture within the valley floor unprofitable to the owner. The regularity of flood pulses also contributes to the fact that human settlements are absent from the valley floor. The relationship between the area of settlements and the distance from the first transect was mainly due to geological and historical reasons. The density of population is significantly higher in the lower part of the river, reflecting the presence of very old and numerous settlements, located on elevated edges of the valley floor. A relation between the area of settlements and the width of water channel results from human settlements on the steep slopes of valley behind large river gaps. In these places the water current is slowed down and deposits are accumulated, and the river channel is shallower and wider.

The area of meadows showed the strongest correlation with floodplain width, which is rather obvious, since a wider floodplain allows more meadows. However, other significant correlations of the area of meadows are worth noticing. The positive correlation with the width of the meander belt and maximum channel depth indicate that the occurrence of meadows is associated with a deep channel showing large lateral activity. This is characteristic of lowland meandering rivers, with high-capacity channels that result in rare and shallower inundation at floods. Meadows, as a way of land use, are

Table 2. Results of stepwise regressions between each variable describing land cover of the Nida valley floor (dependent variable) and all studied variables describing the geomorphic features of the valley floor (independent variables); coefficient b was given with marked statistical significance: * 0.01< p<0.05, *** p<0.001, ns – not significant

| | Human settlements | Meadows | Arable land | Forests | Willow shrubs | Small woods | Unsurfaced country roads | Ditches |
|---|---|---|---|---|---|---|---|---|
| $L$ | 0.35* | ns | ns | ns | ns | ns | ns | ns |
| $K$ | ns | ns | ns | ns | ns | ns | ns | ns |
| $J$ | ns | ns | ns | 0.26* | ns | ns | ns | ns |
| $N_p$ | ns | ns | 0.38* | ns | ns | ns | ns | ns |
| $W_f$ | ns | 0.96*** | 0.25* | ns | ns | ns | 0.60*** | ns |
| $W_{mn}$ | ns | 0.10* | -0.29* | ns | ns | ns | 0.27* | ns |
| $W_{avu}$ | ns | ns | ns | -0.27* | -0.42*** | ns | ns | ns |
| $D$ | ns | ns | ns | -0.27* | -0.25* | ns | ns | ns |
| $B$ | 0.29* | ns | ns | ns | ns | ns | ns | ns |
| $H_{max}$ | ns | 0.13* | ns | ns | ns | -0.26* | ns | ns |

Explanations of symbols:
$L$ – distance along river valley, $K$ – sinuosity index, $J$ – channel gradient, $N_p$ – number of isohypses, $W_f$ – width of floodplain, $W_{mn}$ – width of meander belt, $W_{avu}$ – width of avulsion belt, $D$ – difference in elevation between the channel and the lowest part on woodplain edge, $B$ – width of the channel, $H_{max}$ – maximum channel depth

therefore associated with areas of frequent but shallow floods; such areas are not suitable for any agricultural activity other than hay-making, which requires little investments in terms of money and labour.

This line of reasoning was confirmed by relations between the area of arable land and the geomorphic features of the river valley. First of all, the area of arable land was negatively related to the width of the meander belt. This type of land use was not practised in areas of extensive river meandering either, because of the danger of being destroyed by lateral migration of the channel. The stronger relationship with the number of isohypses indicates that arable land was located on elevations within the valley floor, where the remnants of older geological substratum (usually limestone hills) mainly occur. The flood level falls significantly with the increase in the width of the river valley floor – flood water spreads over a larger area, thus lowering the level. As a result, arable lands can be maintained on fairly low elevations, never flooded owing to the extensive floodplain area.

Riverine forests and willow shrubs covered very small areas of the river valley; their occurrence and area, however, showed similar significant negative correlations. The considerable width of the avulsion belt is characteristic of broad valleys situated further along the course following areas where river valleys cross elevations ($W_{av}$ is highly correlated with $W_f$, $r= 0.56$, $N=60$, $p<0.0001$). Such places are easily accessible for farmers and both forests and scrubs can be exploited. The negative correlation of forest/willow area with the difference in elevation between the channel and the lowest part of the floodplain indicates that the valley floor in these places was not flat but, on the contrary, fairly steep. Such valleys should have steeper slopes, because then the *D* value approaches zero. This way of reasoning was confirmed by a positive relation between the riverine forest area and channel gradient. Steeper valley slopes occurred in those sections of the river where the channel gradient was higher. Such areas usually occur when the river channel approaches the edges of the valley. The area of small woods in agricultural landscape was not related to any geomorphic feature, except for channel depth, which may indicate that they were related to the deep channel of the meandering river.

Correlates of forest coverage can be explained only on the basis of accessibility of the ground to the owner. Small patches of wood are commonly exploited in the area for firewood. In the winter it is difficult to extract logs from steep valley slopes; on the other hand such slopes are useless for any other agricultural activity. Forests, therefore, occur on steep slopes.

Willow shrub cover was inversely correlated with meadow cover. This indicates that willow shrubs occurred on the valley floor at the expense of meadows, and its occurrence was probably restricted to places unsuitable for hay-making.

The length of unsurfaced country roads, which is a good measure of the intensity of human activity within the valley floor, showed a significant relation to the width of the floodplain and also to the width of the meandering belt. While the former relation is rather obvious, the latter one results from the fact that meanders and other water bodies considerably limit access to some areas in the floodplain. This undoubtedly contributes to lengthening the network of unsurfaced country roads.

It is surprising that the length of ditches showed no relation to any geomorphologic feature of the valley floor. This indicates that the distribution of ditches was also not determined by the valley structure but that they were rather planned and constructed on the basis of very local needs.

The above data indicate that under the conditions of extensive agriculture, the morphology of the valley floor significantly influences the way it is managed. The frequency and magnitude of flood events, as well as channel stability, are among the most important factors influencing land cover. Regular floods and the lateral migration of the river determine the predominance of meadows in the valley floor. Also river valley traits related to river activity in the past, influence land use: the width of the meander belt to some degree determines patterns of distribution of unsurfaced country roads. Although human activity within the valley floor appears to be subordinated to the river activity, it should be stressed that the Nida River's type of hydrological regime and the physical structure of the valley floor allow for quite effective and sustainable use of valley resources. Provided that the economic profitability of agricultural production continues, the present level of agricultural use of the valley floor might easily be maintained from the agro technical point of view.

The lack of relation of the artificial drainage systems to the geomorphology of the Nida River valley floor indicates that advanced spatial analysis systems are rarely used in river valley management in Poland. This results in a poor understanding of river function and wrong decisions (Korzeniak et al. 1995; Korzeniak et al. 1996; Zając 1996; Zając et al. 1998). Finding the relationships between the valley floor morphology and these land cover types, which reflect relations between human activities within the valley floor and its structure, would help to manage changes that are bound to occur in the river valleys of Poland in the very near future. It is expected that due to the fall of the economic role of agriculture, particularly its extensive form, vast areas of extensively managed meadows will be abandoned and will become a subject of natural succession. If natural processes working in river valleys were well understood, it would be easy to predict what kind of changes will take place (e.g. in vegetation structure – Jarolimek et al. 2001), what consequences will be brought about and how and when they should be included in spatial planning and river management.

There is some existing knowledge about management that allows the maintenance of high biodiversity levels. With regard to agriculture intensity, the best examples are: the sensitivity of plant diversity to fertilizer application (quickly reducing species richness – Joyce 2001), the influence of appropriate hay mowing and the removal of rare species on the dynamics of populations

(Hegland et al. 2001), and an appropriate application of grazing (corroborating the intermediate disturbance hypothesis – Dupre and Diekmann 2001). In the case of the Nida River, a predicted trend of valley floor management is land abandonment, which results in the overgrowing of the area with shrubs and trees, with some small open areas covered with wetlands. Such a scenario would completely change the character of the valley floor use, from the source of hay to the source of wood. The change will result in a loss of biodiversity associated with open grasslands and wetlands communities. As the whole area of the valley is planned for inclusion into the Natura 2000 network (Baranowski et al. 2001), the most reasonable postulate in order to prevent biodiversity loss here is to relate the maintenance of open agricultural habitats management in the Nida Valley to management plans of the Natura 2000 sites and, if possible, to the Common Agricultural Policy of the European Union, which may supply money for the appropriate management (Witkowski 2001).

Generally, in recent years, the restoration of hydrogenic areas has started to play an important role in environmental management. For instance, several thousand such restorations took place over the past ten years in North America (Budelsky and Galatowitsch 2000). One of the principles of successful river restoration is to help decision-makers in defining realistic restoration objectives. It is important to emphasise that the long-term success of a restoration should be based on process-oriented projects (Harper et al. 1999; Amoros 2001). This objective may be ensured only through projects nested in the broad context of river functioning. One of its principles is interrelation between hydrology, geomorphology and land use. Although a considerable amount of information exists on the influence exerted by the hydrological regime of a river on the geomorphology of its valley floor (Montgomery and Buffington 1998), there is still a need for understanding how the hydrological regime of a river and geomorphic structure of the valley floor influence land use and, in consequence, wildlife. The above data imply that with extensive agricultural use of a river valley, the two most important river valley functions – floods and lateral migration of the riverbed – may confine or moderate human-induced disturbances. It is worth noticing that the land use scheme in the NidaValley is adjusted to its geomorphic structure and natural fluvial processes; not only is the location of hay meadows, arable land and buildings regulated by flood probability or lateral migration of the river channel, but roads and the occurrence of willow shrubs is also adjusted to the topography of the valley floor and associated/underlying processes. This existing model of human/river relationships can be easily and directly applied to sustainable river management practices. Such a wide-scale approach to the riverine environment should be acknowledged both by spatial planning and nature conservation, which may benefit solely from the proper planning of river management.

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